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EREP INVESTIGATION NO. 459
CONTRACT NO. T-4110B

ANALYTIC AEROTRIANGULATION UTILIZING
SKYLAB EARTH TERRAIN CAMERA (S-190B)
PHOTOGRAPHY
NOAA/National Ocean Survey
M. Keller

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SKYLAB A PROPOSAL AEROTRIANGULATION WITH VERY SMALL SCALE
PHOTOGRAPHY - EREP INVESTIGATION NO. 459

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Principal Investigations Management Office
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FINAL REPORT

submitted by

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SURVEY
Rockville, Maryland 20852

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ANALYTIC AEROTRIANGULATION UTILIZING SKYLAB EARTH
TERRAIN CAMERA (S-190B) PHOTOGRAPHY

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PREFACE

This report on the feasibility of utilizing SKYLAB spacecraft photography to provide control for small scale mapping operations was prepared so as to enhance the comprehension of those readers not familiar with the principles of analytic aerotriangulation procedures and the SKYLAB Earth Resources Experiments mission.

All of the work involved in this study was performed in the offices of, and on equipment operated by, the National Oceanic and Atmospheric Administration, National Ocean Survey/Coastal Mapping Division, which is located in the Washington Science Center, Rockville, Maryland. Computer processing was performed on a CDC 6600 computer operated by NOAA and located at Suitland, Maryland.

The author wishes to express his sincere appreciation to Mr. D. Norman and Mr. I. Raborn of the Aerotriangulation Section who performed the photocoordinate measurements, assembled the data, and processed the material through the analytic aerotriangulation system of computer programs. Thanks are due to Commander W. V. Hull, Chief of the Coastal Mapping Division, and to Mr. C. Slama, Chief of the Photogrammetric Research Branch, for allowing the author to provide the time and effort needed to bring this study to a successful conclusion. A final vote of thanks is due Mrs. M. Taglieri, secretary for the Photogrammetric Research Branch, for her patience and diligence in preparing this report for delivery to the National Aeronautics and Space Administration.

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ANALYTIC AEROTRIANGULATION UTILIZING SKYLAB EARTH
TERRAIN CAMERA (S-190B) PHOTOGRAPHY

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ABSTRACT

The objective of this study was to investigate the feasibility of utilizing SKYLAB spacecraft Earth Terrain Camera (S-190B) 1:946,000 scale photography in analytic aerotriangulation procedures to provide low-order, high-density control suitable for small-scale mapping operations.

The long range application is the employment of this technique for coastal zone mapping at medium and small scales, surveys in remote areas, forest and range management, various planning activities, and route location for highways, pipelines, transmission lines, and canals.

The National Oceanic and Atmospheric Administration, National Ocean Survey, (NOAA/NOS), office-identified the locations of 29 photo control points of known position and elevation on a strip of 12 photographs ranging along a 350-mile track from Charlotte, North Carolina, to the Rappahannock River in Virginia. The coordinates of pertinent images on each photograph were then processed through an established analytic aerotriangulation system of computer programs.

The inherent errors in using nonmetric SKYLAB photography and office-identified photo control made it necessary to perform numerous block adjustment solutions involving different combinations of control and weights. The final block adjustment was executed holding to 14 of the office-identified photo control points. The accuracy of the solution was evaluated by comparing the analytically computed ground positions of the 15 withheld photo control points with their known ground positions and also by determining the standard errors of these points from the variance values. A horizontal position RMS error of 15 meters was attained. The maximum observed error in position at a control point was 25 meters.

BACKGROUND

A basic framework of horizontal and vertical geodetic control is essential for coordinating surveys and the mapping of large areas. In the United States, the first- and second-order horizontal and vertical control surveys conducted by the National Ocean Survey of the National Oceanic and Atmospheric Administration provide this basic framework of geodetic control. Additional control surveys of third-order accuracy by various federal and state agencies then subdivide or extend the basic network by triangulation, traverse, and leveling methods in order to bring the control into the areas to be mapped. The control stations established by these surveys are usually monumented for future use.

Photogrammetry is a system of measuring and interpreting data recorded on photographs and is applicable to all sciences that depend on reliable geometric measurements of physical quantities occurring in a fixed or transitory state. The widest application of the photogrammetric art has been in the topographic mapping of the earth's surface, where it provides an alternative and/or supplement to conventional ground methods for establishing geodetic control and mapping geographical features.

Photogrammetric mapping procedures offer certain worthwhile advantages over ground methods, such as: 1. Detailed mapping can be performed more accurately, completely, efficiently, and economically than by ground methods. This advantage increases with the complexity of the details, as, for example, in city and harbor areas and along irregular coasts; 2. otherwise inaccessible areas can be more easily mapped; 3. maps can generally be produced from photographs with less ground control than is necessary for ground methods; and 4. the workload is transferred to the office, where operations are independent of weather and daylight.

Photogrammetry can provide the following primary services:

Provide three-dimensional stereoscopic models of the terrain that can be set in stereoscopic plotting instruments, so that planimetric and topographic details can be compiled from these models.

2. Extend the basic control network directly into the area of photography by using aerotriangulation methods to bridge between the high-order arcs of existing control. This procedure yields primarily fourth-order nonmonumented control and minimizes the need for field work to establish the photo control required to properly orient the stereoscopic models on the plotting instruments.

Aerotriangulation is a photogrammetric technique for deriving the ground coordinates of objects from a set of overlapping aerial photographs that show images of these objects and also of a relatively sparse distribution of other objects whose coordinates are known from classical measurements on the ground. The two principal methods employed to determine the desired three-dimensional ground coordinates for the objects are stereotriangulation and analytic aerotriangulation. Stereotriangulation depends on measurements made on a sequential series of overlapping stereoscopic models formed on a high-precision photogrammetric plotting instrument. Analytic aerotriangulation is a digital solution based on observed coordinates of the images created by pertinent objects appearing on each of the photographs covering the area. The analytic solution possesses a remarkably high accuracy potential as compared to stereotriangulation, because of the advantages accruing from automation, digital accuracy, least-squares adjustment, and freedom from the mechanical discrepancies contributed by the stereoscopic plotting instruments. In addition, the systematic errors such as camera-lens distortion, film shrinkage, atmospheric refraction distortion, etc., can be more effectively eliminated by analytic methods than in stereotriangulation procedures. A disadvantage of the analytical solution is that the computations are complicated and require a large-size electronic computer to contain and process the large volume of data with economy and speed.

THE MATHEMATICAL BASIS OF ANALYTIC AEROTRIANGULATION

Several different variations in analytical aerotriangulation techniques have evolved. However, all of the methods basically consist of writing equations which relate the unknown elements of exterior orientation of each photograph to camera constants and refined x and y image coordinates observed on a comparator. The equations are solved for the unknown camera orientation parameters and the ground coordinates for each object creating observed images on the photographs. Since more observational information is normally available than is required for a unique solution, the method of least squares is used to obtain the most probable values of the unknown parameters in such a fashion that the sum of the squares of the residual observational discrepancies is a minimum.

The observation equations must be linear with respect to the unknown independent parameters; otherwise, a direct solution of the equations becomes difficult. If the mathematical model is nonlinear, as most photogrammetric problems are, a Taylor's expansion series is usually employed to linearize the equations. The computation requires initial approximations of the unknown parameters and is iterative because the second and higher degree terms of the Taylor's series are neglected to simplify.

the mathematics. The least squares solution provides corrections to the approximate values of the parameters. If the initial approximations are coarse, the corrections are added to them, giving fresh and improved approximations for a new solution. Least squares is used again to provide another set of corrections, and the procedure is repeated until some criterion of convergence is satisfied.

The most commonly used analytic methods are designed to enforce one of two conditions: coplanarity or collinearity. Coplanarity is the condition that the two perspective centers of an overlapping pair of photographs, any object point, and its corresponding image points on the two pictures all lie in a common plane; i.e., the rays passing through the two camera stations should intersect at a single object point. The purpose of the computation is to minimize the distance between the two rays at the object location. The observation equation utilized in each object space angle thus contains the four residual errors, v_x , v_y on first photo and v_x , v_y on second photo, involved in measuring the x and y image coordinates on each picture. This causes the solution to become cumbersome and difficult to solve properly when the object occurs on several or more photographs.

Collinearity is the condition that every object, its photographic image, and the camera exposure station must lie on a common straight line, as defined by the method of least squares in which the sum of the squares of the residual errors of image coordinate measurement is minimized. Two observation equations are written for every image and, except for the few control station images, contain only one residual error, v_x or v_y , in each equation.

This simplifies the application of least squares so that any number of photographs can be routinely accommodated.

The principle of collinearity provides the basis for the NOS method of analytic aerotriangulation. The condition is utilized in an iterative manner to determine incremental corrections to initial approximations for the unknowns, which are reasonably close to the correct values.

COLLINEARITY CONDITION FORMULATION

The well known equations of collineation comprising the projective transformation are:

$$\frac{x}{z} = \frac{(X-X_0) a_{11} + (Y-Y_0) a_{12} + (Z-Z_0) a_{13}}{(X-X_0) a_{31} + (Y-Y_0) a_{32} + (Z-Z_0) a_{33}}$$

$$\frac{y}{z} = \frac{(X-X_0) a_{21} + (Y-Y_0) a_{22} + (Z-Z_0) a_{23}}{(X-X_0) a_{31} + (Y-Y_0) a_{32} + (Z-Z_0) a_{33}}$$

where the a - terms are the nine elements of the rotation matrix relating the x, y, z image coordinate system to the X, Y, Z ground coordinate system of the objects, and X_o, Y_o, Z_o are the coordinates of the camera station expressed in the ground coordinate system.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} \cos \phi \cos \kappa & \cos \omega \sin \kappa & \sin \omega \sin \kappa \\ +\sin \phi \cos \kappa & +\sin \omega \sin \phi \cos \kappa & -\cos \omega \sin \phi \cos \kappa \\ -\cos \phi \sin \kappa & \cos \omega \cos \kappa & \sin \omega \cos \kappa \\ -\sin \phi \sin \kappa & -\sin \omega \sin \phi \sin \kappa & +\cos \omega \sin \phi \sin \kappa \\ \sin \phi & -\sin \omega \cos \phi & \cos \omega \cos \phi \end{bmatrix}$$

A Taylor's expansion series is applied to the transcendental collinearity equations to obtain linearized observation equations, which can then be solved for the linear independent unknowns by the application of least squares. The complete form of the linearized observation equations is:

$$v_x = (P_{11} + P_{12}dw + P_{13}d\phi + P_{14}d\kappa - P_{15}dX_o - P_{16}dY_o - P_{17}dZ_o + P_{15}dX + P_{16}dY + P_{17}dZ) / A_3 B$$

$$v_y = (P_{21} + P_{22}dw + P_{23}d\phi + P_{24}d\kappa - P_{25}dX_o - P_{26}dY_o - P_{27}dZ_o + P_{25}dX + P_{26}dY + P_{27}dZ) / A_3 B$$

where the nine terms dw through dZ are incremental corrections to be applied to initial approximations of the unknowns. These two equations occur for each image on each photograph. Block adjustment requires the presence of all nine terms, whereas the space resection computations use only the first six terms dw through dZ_o . Sufficient photographs and images are needed to provide at least as many equations as there are unknowns to be computed. The solution is iterative and terminates when the incremental corrections to the angular parameters are smaller than the observed precision.

THE NATIONAL OCEAN SURVEY ANALYTIC AEROTRIANGULATION SYSTEM

Aerial Photography

The Coastal Mapping Division of NOS utilizes well calibrated precision aerial cameras to secure the near vertical aerial photography required for its photogrammetric operations. These cameras include the Wild RC-8, 6-inch focal length camera and the Wild RC-10 camera equipped with interchangeable 6-inch and 3.5-inch focal length cones.

The cameras are mounted in two aircraft operated by the Division; one being a DeHavilland Buffalo, while the other is an Aero Commander 690A. The Buffalo is a twin-engined turboprop craft,

having a cruising speed between 120 and 180 knots at altitudes up to 32,000 feet. Its cruising range is 10 hours. The cabin is unpressurized, thereby requiring the crew to use oxygen above 10,000 feet. The Buffalo has been modified to simultaneously accommodate three aerial cameras mounted in three hatches. The plane is used on nearly all photographic missions conducted by the Division.

The Aero Commander 690A is a leased aircraft, employed to obtain photography for airport surveys. It is a twin-engined turbo-prop craft, having a cruising speed between 100 and 270 knots at altitudes up to 32,000 feet. Its cruising range is five hours. The pressurized cabin permits the crew to operate without relying on oxygen. However, this requires the photography to be taken through an optically flat glass window which covers the single hatch. A backup oxygen supply is available that permits aerial photography to be taken without the window in place over the hatch.

Photo Control Points

In order to implement analytic aerotriangulation methods, it is necessary to establish sufficient photo control to properly orient the aerial photography. Photo control refers to the establishment of horizontal positions and/or elevations with respect to the basic framework of geodetic control monuments of carefully chosen ground objects, which create sharp, distinct, and easily identifiable point images on the photographs. The positions and/or elevations are determined from the monumented control network by third- and fourth-order triangulation, traverse, and leveling methods. The photo control points selected in the field are usually prominent natural or cultural features providing sharp imagery on the overlapping photographs. Such examples are road intersections, fence-line intersections, lone trees, corners of buildings and wharves, and smaller stacks or towers.

For the more precise photogrammetric surveys, the placement of specially prepared targets on the control points, prior to photography, is desirable for facilitating accurate office identification of the photo control points. The targets are symmetrical in design, centered on the photo control points, and are of sufficient size to show on the photography. The targets are usually in the shape of a Y or a cross.

Pass Points

In analytical control extension, pass points are established in the nine standard relative orientation locations on each photograph. The pass points may be easily identifiable point images similar to those selected as photo control points. Usually,

however, the pass points are simply holes drilled into the photographic emulsion, with the Wild PUG-2 stereoscopic point transfer device in areas providing an optimum stereoscopic perception. On 60 percent overlap photography, one ground object can appear as a pass point image on three successive photographs of a strip.

NOS programs permit two pass points to be used in each relative orientation location, even though only one pass point is sufficient to provide all of the data needed for the analytic computations. Then, if one of the pass points in a relative orientation location should exhibit an excessively large residual discrepancy during the solution, it can be discarded and its companion pass point substituted in its place.

Marking and Photocoordinate Measurement

A stereoscopic point transfer device, such as the Wild PUG-2, is first used to select, mark, and transfer suitable photo control and pass point images to adjacent photographs. The coordinates of each image on the photograph transparency are then measured to micron accuracy by either a digitized Mann monocomparator or by a stereocomparator, such as the Wild STK or the Zeiss PSK.

The use of a monocomparator means that the images on only one plate can be measured at a time. It, thus, is necessary to use a stereoscopic point transfer device to mark and transfer all images to every photograph. Stereocomparators, however, can simultaneously measure the photocoordinates of corresponding images on a stereoscopic pair of photographs. As a consequence, it is necessary to mark (drill) all of the images on only one photograph in each strip in order to specifically identify the image for measurement purposes. The drilled image can then be stereoscopically transferred to the second photograph and measured with the stereocomparator without actually ever drilling the image on the second photo. Since the images are drilled on only one plate, it is not necessary to use a stereoscopic point transfer device to mark the images. In practice, the PUG device is needed only as a means for transferring the images to any adjoining strips.

In essence, a stereocomparator consists of two mechanically united monocomparators. A monocomparator is, therefore, more accurate than a stereocomparator. In practice, however, the need for additional PUG operations with a monocomparator results in the accuracy of the monocomparator-PUG combination, being about equal to that of the stereocomparator.

After the photocoordinates have been measured, the data is submitted for processing through the series of computer programs comprising the analytic aerotriangulation system.

Computer Processing

The analytic aerotriangulation system developed at NOS consists of five programs: (1) Image coordinate refinement and three-photo orientation, (2) strip adjustment to ground control, (3) secant plane coordinate transformation, (4) block adjustment, and (5) accuracy analysis.

(1) Image Coordinate Refinement and Three-Photo Orientation:

To obtain the highest possible degree of accuracy in analytical solutions, measured photocordinates must be corrected for systematic errors which cause distortions in the image positions. The first program, therefore, begins with a refinement of the raw x and y image coordinates measured on each photograph on the comparator. The popularity of making positive prints of the photographs on glass plates (diapositives) has declined in recent years. Today polyester plastic bases are used because they provide a dimensionally stable base film that is much less sensitive to humidity, temperature, and laboratory processing. The photocordinates observed on the photograph transparency are corrected for the systematic distortions introduced by the comparator, film shrinkage, camera lens, and atmospheric refraction. The problem of earth curvature is recognized in the third program, in which the ground coordinates of all objects are expressed in a geocentric, three-dimensional secant plane system that takes earth curvature into account.

The refined image coordinates are punched out to serve as input to the block adjustment program (4). The refined image coordinates theoretically should be nearly all free of systematic error and contain only residual observational discrepancies in them.

The program then proceeds to the three-photo camera orientation phase, which comprises an interrelated geometric fitting of the photographs based only on the refined image coordinates and is entirely independent from any ground control data. The computation is iterative and derives the orientation of each photograph relative to the previous two in the strip. It also determines the positions of all pertinent objects in a three-dimensional coordinate system at the scale of the photography. The collineation principle is imposed in a least squares solution that minimizes the discrepancies in the observed image coordinates. The residual errors are analyzed by the computer, which discards those images exhibiting excessively large discrepancies. The removal of these blunders provides "clean" image coordinate data for all subsequent computations.

(2) Strip Adjustment to Ground Control: The analysis of three photographs at a time automates the joining of the separate triplets into a continuous strip and develops a set of model

coordinates, which are analogous to the product obtained from conventional stereotriangulation on stereoscopic plotting instruments. The horizontal and vertical strip adjustment program transforms the model coordinate data into the prevailing ground control coordinate system by fitting to control stations through the application of polynomial equations and least squares. Any large residual discrepancies appearing in the resulting adjustment are corrected in order to obtain provisional ground position data that are free of blunders prior to entering the block adjustment computation.

The analytic computations may be terminated after strip adjustment or may continue through block adjustment, depending on the desired accuracy. While block adjustment can be performed without actually using the three-photo orientation and strip adjustment programs, these preliminary programs are employed in practice to furnish improved and complete data for the block adjustment in an effort to reduce the time and cost of "debugging" and computer operations.

(3) Secant Plane Coordinate Transformation: If maximum accuracy is desired, the provisional ground coordinates are first transformed into a geocentric and then into a special secant plane system that takes earth curvature into account. The block adjustment solution is performed using these secant plane coordinates for the objects, together with the previously obtained refined image coordinates. The secant plane transformation program is designed to operate in its inverse mode so that given secant plane coordinates can be transformed back into the prevailing ground coordinate system.

(4) Block Adjustment: This program permits the simultaneous solution of the absolute orientation (three linear elements of position and three angular elements of orientation) of all photographs in a block of overlapping strips of photography. Only the pass points and control station objects contribute equations and thus influence the least square orientation solution. Their finalized ground coordinates are computed simultaneously, along with the absolute orientation of all the photographs in the block. Those objects that are not pass points or control stations do not contribute equations and thus do not influence the orientation solution. The finalized camera parameters from the orientation solution and the refined image coordinates are used to compute the final ground X, Y, Z coordinates for these other objects by intersection. After the block adjustment is completed, the adjusted secant plane coordinates are transformed back into the original ground coordinate system by applying the secant plane transformation in its inverse mode.

The major task of the block adjustment program is the solution of the large number of simultaneous equations in a least square manner that efficiently utilizes the memory capacity of the computer. The largest program written at NOS can accommodate as many as 600 photographs in a single simultaneous least square adjustment. Some 36,000 observation equations containing about 10,000 unknowns may be generated in developing the normal equations. The number of objects whose final ground positions can be computed in the block adjustment solution is unlimited.

All of the analytic programs have been written to operate on the CDC 6600 computer. To date, the largest block adjustment problem processed through the computer contained 180 photographs. The solution involved over 15,000 observation equations and about 4,500 unknowns. The CDC computer running time for the least square block adjustment was less than five minutes.

(5) Accuracy Analysis: In order to appreciate fully the accuracy potential of the system, and the error values at test points, a final computer program is used to develop the inverse of the matrix of normal equations, the variances, and the standard errors in centimeters in X, Y, and Z at all the points used throughout the area. The error $E = Qe$ at any point is composed of two components where Q is the variance at the point as derived from the inverse, and e is the standard error of unit weight for the problem based on program (4). The quantity Q is affected by the geometry of the system, including the amount and distribution of control points, and e is related to the precision of the steps of the system including image resolution.

Accuracy of the NOS Analytic Aerotriangulation System

A significant increase in accuracy results when analytic aerotriangulation computations are continued through block adjustment. Studies conducted at NOS have yielded the following accuracy results:

The horizontal position root-mean-square error in meters when using film cameras is $S10^{-5}$ where S is the denominator of the photography scale fraction. If a glass plate camera is used, and the pass points are premarked, then the expected RMS error in meters is about $1/5$ of $S10^{-5}$.

The vertical and horizontal errors are equal for a 3.5-inch focal length camera (base-height ratio = 1), whereas the vertical errors may be about 1.5 times larger than the horizontal errors for a 6-inch focal length camera (base-height ratio = 0.6).

This accuracy is achieved when: (a) 60 percent forward and side overlap exists between the photographs in the block; (b) a strong network of horizontal and vertical photo control exists around the perimeter of the area, along with a few interior vertical photo control stations; (c) all of these stations are premarked prior to photography; (d) the block consists of at least three strips of photography.

Note: The rms errors are considered to be essentially equal to the standard error of unit weight. The rms value therefore has a 68 percent reliability. The 90 percent reliability is about 1.6 times larger, and the 99 percent value is about 2.6 times larger.

SKYLAB

The SKYLAB mission was planned and implemented to determine the capability of man and spacecraft to conduct medical, solar physics stellar and solar astronomy, and Earth observational programs. On May 14, 1973, the National Aeronautics and Space Administration successfully launched the SKYLAB manned orbital facility into a nearly circular 234-nautical mile (435 km) orbit above the earth (SL-1). The first three-man team of astronauts manned the laboratory for 28 days, beginning on May 25, 1973, (SL-2); the second team occupied the facility for 60 days, starting on July 28, 1973 (SL-3); and the third team followed on November 16, 1973, for an 85-day mission (SL-4). The 50-degree inclination of the orbit permitted the astronauts to view 75 percent of the earth's surface--the area between 50 degrees North and 50 degrees South--and to pass over a given point once every five days.

The 100-ton SKYLAB spacecraft is actually a hollowed-out third stage of a Saturn rocket, originally assigned to the U.S. moon program, which has been converted to provide living and working space for the astronauts. Within the SKYLAB space station are complex scientific and technical instruments that will enable them to conduct investigations directed toward the accomplishment of medical experiments, solar astronomy experiments, technical experiments, and earth resources experiments as follows:

- a. To study man: Medical experiments will determine physiology conditioning and performance capability in real time, in zero-gravity environment, for long-duration space flight.
- b. To study the sun: Solar astronomy experiments will provide a synoptic survey and study of special phenomena on the solar disk in X-ray, ultraviolet (uv), and visible spectral wavelengths.
- c. To study space technology: Technical experiments will evaluate coating degradation, spacecraft contamination, manufacturing and repair techniques, and manned-maneuvering units.
- d. To study the Earth: Earth resources experiments will provide a synoptic survey of selected areas on the earth in visible, infrared (IR), and microwave spectral wavelengths.

EARTH RESOURCES EXPERIMENTS

Among the various SKYLAB investigations, the Earth Resources Experiments are unique in that they are concerned directly and exclusively with earth rather than space applications. The energy reflected and radiated from various plants, ground scenes, and bodies of water has specific spectral distributions, not only in the visible but in the infrared and microwave portions of the electromagnetic spectrum. These spectral "signatures" can be detected by utilizing instruments ranging from a multiband camera to infrared spectrometers and microwave radiometers. Six such electronic and photographic remote sensing systems for observing the earth have been combined into the Earth Resources Experiment Package (EREP) and mounted on board the manned SKYLAB orbital facility. Since SKYLAB is a solar-pointing, inertially stabilized spacecraft, it must be maneuvered into an earth-oriented mode in order to use the EREP sensors.

The EREP is designed as a facility with the vantage point of space for use by a variety of users, in a wide range of applications to earth resources management. The EREP sensors can be operated singly or in various combinations, depending on the scientific requirements or other factors, such as weather and/or vehicle capability limits. Data are recorded on tape and film so that each team of astronauts can bring back to earth the data recorded during its stay on the spacecraft. After initial processing at the Johnson Space Center in Houston, Texas, the data are distributed to more than 200 SKYLAB principal investigators.

The data acquired with the EREP sensors is expected to be useful for studies and analysis related to most Earth Resources disciplines. For example, these observations can be applied to research in agriculture, forestry, ecology, geology, geography, meteorology, geomorphology, hydrology, hydrography, oceanography, cartography, and similar fields for the purpose of identifying agricultural species; measuring growth rates; assessing crop vigor and stress; classifying land use; determining land surface composition and structure; mapping snow cover and assessing water runoff characteristics; mapping pollution, shorelines, and estuaries; evaluating sea roughness conditions; and similar projects.

The SKYLAB earth resources program has been structured into ten major disciplines as outlined in Table 1 below.

TABLE 1.
EREP PROGRAM STRUCTURE

100	<u>AGRICULTURE/RANGE/FORESTRY</u>	600	<u>COASTAL ZONES, SHOALS, AND BAYS</u>
	Crop inventory		Circulation and pollution in bays
	Insect infestation		Underwater topography and sedimentation
	Soil type		Bathymetry
	Soil moisture		Coastal circulation
	Range inventory		Wetlands ecology
	Forest inventory		
	Forest insect damage		
200	<u>GEOLOGICAL APPLICATIONS</u>	700	<u>REMOTE SENSING TECHNIQUES DEVELOPMENT</u>
	Mapping		Pattern recognition
	Metals exploration		Microwave signatures
	Hydrocarbon exploration		Data processing
	Rock types		Sensor performance evaluation
	Volcanoes		
	Earth movements	800	<u>REGIONAL PLANNING AND DEVELOPMENT</u>
300	<u>CONTINENTAL WATER RESOURCES</u>		Land use classification techniques
	Ground water		Environmental impacts - special topics
	Snow mapping		State and foreign resources
	Drainage basins		Urban applications
	Water quality		Coastal/plains applications
			Mountain/desert applications
400	<u>OCEAN INVESTIGATIONS</u>	900	<u>CARTOGRAPHY</u>
	Sea state		Photomapping
	Sea/Lake ice		Map revision
	Currents		Map accuracy
	Temperature		Thematic mapping
	Geodesy		
	Living marine resources	000	<u>USER AGENCY TASKS</u>
500	<u>ATMOSPHERIC INVESTIGATIONS</u>		Department of the Army
	Storms, fronts, and clouds		Department of the Interior
	Radiant energy balance		
	Air quality		
	Atmospheric effects		

Each SKYLAB investigation has been given a three-digit task number, according to the subdisciplines in which work is done. In addition, every EREP study site has been given a three-digit designation that defines its geographic location.

DESCRIPTION OF EARTH RESOURCES EXPERIMENT PACKAGE (EREP) SENSORS

An extensive description of the photographic remote sensing system is given below, along with a brief description of the other EREP sensors.

Multispectral Photographic Facility (S-190A and S-190B)

The experiment objective is to photograph the earth's surface in a spectral range that includes visible light and extends into the near-infrared, with sufficient resolution and spectral definition to allow detailed analysis and interpretation by specialists in a variety of earth resources disciplines.

The facility is arranged in two parts. S-190A consists of an array of six 70-mm film cameras, precisely matched and boresighted, so that photographs from all six cameras will be accurately in register. Thus, all of the features seen in one photograph can be simultaneously aligned with the same features in the photographs from the other cameras. A combination of black-and-white and color films is used in conjunction with selective filters for spectral analysis, allowing comparison with imagery obtained with the IR spectrometer (S-191) and multispectral scanner (S-192) and with the Earth Resources Technology Satellite (ERTS). The camera array is mounted behind an optical glass window, just forward of the radial docking hatch in the Multiple Docking Adapter (MDA).

The second part, S-190B Earth Terrain Camera, consists of a single camera that is located behind an optical glass window in the Scientific Airlock (SAL) on the antisolar side of the Orbital Workshop (OWS). This camera is an adaptation of the Lunar Topographic Camera carried on the Apollo 14 mission.

Controls for the six-camera array are integrated with the controls for the other EREP sensors located in the MDA. However, the Earth Terrain Camera controls are mounted on the side of the camera housing and are independent of other EREP sensors.

For earth resources operations, SKYLAB departs from its normal solar orientation to an orbital mode that provides for continuous pointing of the cameras and other sensors at the ground directly below. The crewmen load film, install filters, set up the camera controls, remove the covers from the camera ports, uncover the window, install the Earth Terrain Camera in the Scientific Airlock, and make other preparations for camera operations.

The exposed film is the primary data returned at the end of each SKYLAB mission, for processing and analysis on the ground.

S-190A

The EREP multispectral photographic camera consists of six high-precision 70-mm film cameras with matched distortion and focal length. The f/2.8 lenses have a focal length of six inches. The camera has a field-of-view of 21.2 degrees across the flats based on the photographic format size of 2.25 inches square and provides ground coverage of 163 km square per frame at a scale of 1:2,850,000. The system is designed for the following wavelength/film combinations:

0.5 to 0.6	um	PAN X B&W
0.6 to 0.7	um	PAN X B&W
0.7 to 0.8	um	IR B&W
0.8 to 0.9	um	IR B&W
0.5 to 0.88	um	IR COLOR
0.4 to 0.7	um	HI-RES COLOR

S-190B

The body of the Earth Terrain Camera (ETC) is an extensively modified Hycon KA-74 reconnaissance camera body with a bidirectional focal-plane shutter and vacuum film flattening. The ETC is equipped with an f/4 lens having a focal length of 460 mm (18 inches), color correction, and a maximum radial distortion of 10 um. Forward image-motion compensation is provided by rocking the entire camera in its mount during the exposure. The ETC has a limited field-of-view of 14 degrees across the flats, based on the photographic format size of 4.5 inches square and provides ground coverage of 109 km square per frame at a scale of 1:946,000. The system is designed to utilize the following film types:

TYPE	DESCRIPTION	WAVELENGTH, um	ESTIMATED GROUND RESOLUTION
			(at low contrast)
SO-242	Aerial color, high resolution	0.4 to 0.7	70 ft. on ground
EK 3414	High-definition aerial B&W	0.5 to 0.7	55 ft. on ground
EK 3443	Aerochrome IR, color	0.5 to 0.88	100 ft. on ground

The ETC is not a metric camera in the photogrammetric sense. Because the image frame is a part of the removable film magazine and because of the use of a focal-plane shutter, the geometric quality of the photographs is limited. The shutter motion is in the flight direction for one exposure, and opposite the flight direction for the next exposure. This causes a slight scale compression or stretching in the flight direction, depending

upon errors in the FMC. The principal point cannot be precisely located, and therefore analytical applications are limited. When the camera is operated for 60 percent overlap, the base-height ratio is only 0.10; thus, any stereoscopic height measurements from the photographs have especially limited accuracy.

In spite of these limitations, the ETC represents a significant advance in camera systems for earth resources observations from space. The ETC provides photography having a ground resolution from 3 to 20 times better than that of any other space photographic system previously used. As a consequence, the primary objective of the ETC is to obtain high-resolution stereoscopic photography to support the other EREP sensors by aiding in the interpretation of data gathered by them.

Note: A more complete discussion of the ETC is given in a paper by J. D. McLaurin, U.S. Geological Survey, entitled THE SKYLAB S-190B EARTH TERRAIN CAMERA--see Appendix A.

Infrared Spectrometer (S-191)

The primary objective of this experiment is to make a fundamental evaluation of the applicability and usefulness of sensing earth resources from orbital altitudes in the visible through near-infrared and in the far-infrared spectral regions. Correlation of SKYLAB spectrometer data, with data gathered by ground-based and aircraft sensors, will ensure that the radiance from the target and its characteristics will be accurately established. The extent to which the effects of the atmosphere can be removed from the data is a study of particular importance to all remote sensors, and this accuracy will be quantitatively tested. In addition, the parameters describing the atmosphere at the time of acquisition will be collected.

The filter wheel spectrometer has a 1-milliradian field-of-view, and its spectral range coverage is from 0.4 to 2.4 and 6.2 to 15.5 micrometers. The spectrometer has a pointing and tracking capability of 45 degrees forward, 10 degrees aft, and 20 degrees to the side of the ground track. The astronaut uses the view-finder/tracker to acquire and track target sites during data acquisition, which are in his field of view for less than a minute. The primary data are recorded on magnetic tape and are returned with each crew rotation.

Multispectral Scanner (S-192)

The primary objective of this experiment is to assess the feasibility of multispectral techniques for remote sensing of earth resources from space. Specifically, attempts will be made at spectral signature identification and mapping of ground test sites in agriculture, forestry, geology, hydrology, and oceanography.

The basic instrument design is that of an optical mechanical scanner using an image plane scanning mirror, with a folded reflecting telescope used as a radiation collector. The scanner operates in 13 spectral intervals of the visible, near-infrared, and thermal-infrared regions of the spectrum ranging from 0.41 to 12.5 μm . The primary data are recorded on magnetic tape and are returned with each crew rotation.

The spectral range covered by the scanner overlaps the range of the multispectral cameras (S-190) and the IR spectrometer (S-191), permitting a cross-check of results deduced from these three systems. In addition, the IR spectrometer may provide atmospheric density profiles useful for correcting the primary causes of atmospheric attenuation of the scanner data.

Microwave Radiometer/Scatterometer and Altimeter (S-193)

The objectives of this experiment are simultaneous measurement of the radar differential backscattering cross section and passive microwave thermal emission of the land and ocean on a global scale, and engineering data for use in designing radar altimeters.

The microwave radiometer/scatterometer experiment is a combination of an active radar scatterometer and passive radiometer. The radar backscattering cross section measurement gives a measure of the combined effect of the dielectric properties, roughness, and brightness temperature of the terrestrial surface. Information over test sites is obtained by the NASA earth resources aircraft for validation and extrapolation of spaceborne measurements. All data are recorded on magnetic tape.

L-Band Radiometer (S-194)

The experiment objective is to obtain measurements of the brightness temperature of the earth's surface along the spacecraft track. The L-band radiometer has basically the same operating principle as the radiometer part of the microwave radiometer/scatterometer experiment, except that the operating frequency is changed from 13.9 GHz to 1.42 GHz. A function of the experiment is to supplement the measurement results of Experiment S-193 by taking into consideration the effect of clouds on radiometric measurements. By using two frequencies (S-193 at 13.9 GHz and S-194 at 1.42 GHz) simultaneously in measurements, corrections can be made on radiometric data to include the cloud effects. All data are recorded on magnetic tape.

A summary of the SKYLAB EREP sensor characteristics is given in Table 2.

Table 2.
SKYLAB
EREP SENSOR CHARACTERISTICS

SENSOR	DESCRIPTION	SPECTRAL COVERAGE	SPECTRAL RESOLUTION	GROUND COVERAGE	SPATIAL RESOLUTION
S-190(A) MULTISPECTRAL PHOTOGRAPHIC CAMERA	SIX 70mm CAMERA MATCHED DISTORTION AND FOCAL LENGTH (15.2cm) 12 METERS REGISTRATION 18 FILTERS 21° FOV	MICROMETERS .5 - .6 PANX B&W .6 - .7 PANX B&W .7 - .8 IR B&W .8 - .9 IR B&W .5 - .88 IR COLOR .4 - .7 HR COLOR	0.1 MICROMETERS	163 x 163 Km	APPROX. 24m TO 68m *
S-190(B) EARTH TERRAIN CAMERA	460 mm FOCAL LENGTH 114mm FILM FORMAT 3 FILTERS	0.4 TO 0.7 H. R. AERIAL COLOR 0.5 TO 0.88 IR COLOR 0.5 TO 0.7 HIGH DEFINITION AERIAL B & W	0.1 MICROMETERS	109 X 109 Km	APPROX. 10m TO 38m *
S-191 INFRARED SPECTROMETER	POINTED BY CREW FILTER WHEEL ONE SEC. SCAN RATE ONE mRAD FOV CRYOGENIC COOLER 16mm CAMERA	0.4 TO 2.4 AND 6.2 TO 15.5 MICRO- METER	1% TO 4%	0-45° FWD 0-20° SIDE 0-10° REAR	0.44 Km SPOT
S-192 MULTISPECTRAL SCANNER	IMAGE PLANE SCANNER 6000RPM SCAN MIRROR CRYOGENIC COOLER HgCdTe DETECTORS (13 USED) 0.186 mRAD FOV	0.4 TO 2.35 AND 10.2 TO 12.5 MICROMETERS	13 BANDS: 0.04 TO 0.1 MICROMETERS	68 Km SWATH	80 x 80 m SPOT
S-193 MICROWAVE RADIOMETER/SCATTEROMETER AND ALTIMETER	1.1m PARABOLIC ANTENNA TWO AXIS GIMBAL (0-40° IN FIVE STEPS) 1.5° FOV DUAL POLARIZATION ALTIMETER NADIR SEEKER	13.8 TO 14.0 GHz (13.9 GHz CENTER FREQUENCY)	SCAT RECEIVER: FIRST IF: 500 MHz SECOND IF: 50 MHz RAD RECEIVER: SINGLE FREQUENCY	0-48 FWD 0-48 SIDE	11 x 11 Km SPOT
S-194 L-BAND RADIOMETER	1 m PHASED ARRAY (8 x 8 ELEMENTS) COLD AND HOT REF.	1,400 TO 1,427 GHz	18 MHz FROM CENTER FREQUENCY	111 Km CIRCLE	111 Km SPOT

NOTES: FOV = FIELD OF VIEW

* - DOES NOT INCLUDE LOSS DUE TO ATMOSPHERE EFFECTS OR FILM PROCESSING.

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IDENTIFICATION OF THE NOAA/NOS INVESTIGATION

The NOAA/NOS proposal to perform analytic aerotriangulation utilizing SKYLAB photography has been designated as SKYLAB EREP INVESTIGATION NO. 459 and was performed under NASA PURCHASE ORDER T-4110B. The task-site identification number for the study is 931651 in which 931 classifies the task as being in the CARTOGRAPHY MAP ACCURACY discipline, and 651 identifies the test site as the CARETS AREA, which runs from Charlotte, North Carolina, northeast to Delaware Bay.

The official NASA description of this investigation is as follows:

- 931 Investigate the feasibility of utilizing spacecraft (S-190B) imagery for analytic aerotriangulation methods to provide low-order, high-density control network suitable for small-scale mapping applications.

Employ this technique for coastal zone mapping at medium and small scales, surveys in remote areas, forest and range management, various planning activities and route location for highways, pipelines, transmission lines, and canals.

SKYLAB S-190B EARTH TERRAIN CAMERA (ETC) PHOTOGRAPHY

SKYLAB S-190B photography was secured over the test site, during orbit 36, on September 12, 1973 (SL-3). The film used in the ETC was Aerial-Color, High-Resolution S0-242. Second generation transparencies, positive in tone and direction when viewed on the emulsion side, were made from the original film by printing emulsion-to-emulsion in contact. These 1:946,000 scale, 4.5 x 4.5-inch transparencies and 9 x 9-inch contact paper prints were provided to the Coastal Mapping Division of the National Ocean Survey for processing through the analytic aerotriangulation system.

The photography consisted of a strip of 19 photographs ranging along a 500-mile track from Charlotte, North Carolina, (frame 86-288) to Atlantic City, New Jersey, (frame 86-306). A break in the required 60 percent overlap reduced the usable strip of photography to 12 photographs along a 350-mile track from Charlotte, North Carolina, (frame 86-288) to the Rappahannock River in Virginia (frame 86-299).

Although the photography provided sharp high-resolution imagery, the selection of pertinent images for measurement on the Wild STK stereocomparator was hampered by the extensive cloud cover occurring on most of the 11 stereoscopic models comprising the analytic strip.

Despite the cloud cover, 29 photo control points of known position and elevation were office-identified on the SKYLAB photography. Road intersections were located by stereoscopically examining the photographs and comparing them with 1:24,000 scale USGS quadrangles covering the area. The Geographic Positions were scaled from the quadrangles by linear interpolation between the 2' 30" intervals shown on each quadrangle. The scaling was performed five times and a mean Geographic Position computed. In addition, aeronautical aids to navigation and airport runway ends were identified on the pictures, and their positions and elevations determined from data secured by the Coastal Mapping Division under its Airport Obstruction Chart Survey program. The office-identified road intersections and aeronautical aids provided images slightly superior in quality to that of the office-identified airport runway ends. The locations of these photo control points or stations on the ETC photographs is shown in Figure 1. Table 3 describes the stations and their approximate accuracy.

All of the photo control stations were at least 1/4-inch in from the sides of the 1:946,000, 4.5 x 4.5-inch transparencies. Twenty-five of the stations appeared on only two consecutive overlapping photographs in the strip, while four stations appeared on three consecutive photographs. The location of the camera clock within the photographic format prevented two control stations from creating imagery on three consecutive overlapping pictures.

PASS POINTS

Two pass points were established in the nine conventional relative orientation locations on each photograph. The pass points were drilled into the transparency emulsion with the Wild PUG-2 stereoscopic point transfer device in areas providing an optimum stereoscopic perception. As a consequence of the intrusion of the camera clock into the photographic format, it was necessary to set the pass points along the bottom easterly edge of the strip at least 1/2-inch in from the sides of the transparencies.

The two pass points were used in the preliminary analytic aerotriangulation programs consisting of the Image Coordinate Refinement and Three-Photo Orientation program, the Secant Plane Coordinate Transformation program, and the Strip Adjustment to Ground Control. However, only one of the two pass points in each relative orientation location was used in the block adjustment of the strip.

MARKING AND PHOTOCOORDINATE MEASUREMENT

The Wild PUG-2 stereoscopic point transfer device was used to select and mark only the pass points by drilling holes into the photographic emulsion at these images using a 60-micron diameter diamond-tipped

TABLE 3.
 ACCURACY OF OFFICE IDENTIFIED CONTROL
 USED IN
 BLOCK ADJUSTMENT

CONTROL STATION NUMBER	APPROXIMATE HORIZONTAL ACCURACY (METERS)	APPROXIMATE VERTICAL ACCURACY (METERS)	DESCRIPTION
288100 288101 293100 294102 295100 299100	15	5.0	AERONAUTICAL AIDS Horizontal and vertical positions from Airport Surveys, NOS.
288110 288111 290110 296111	5	3.0	ROAD INTERSECTIONS Horizontal and vertical positions from 1:24,000 scale USGS quadrangles.
288201 288202 290201 290111 292110 292111 293110 296201 296110 298110 299110 299111	5	0.5	ROAD INTERSECTION SPOT ELEVATIONS Horizontal and vertical positions from 1:24,000 scale USGS quadrangles.
288120 291120 291121 293120 293121 297120 297121	1	0.3	CENTERLINE RUNWAY ENDS Horizontal and vertical positions from Airport Surveys, NOS.

drill. The photo control point images were not drilled in order to preserve the sharpness of the imagery.

The measurement of the x and y photocordinates for the pass points and control stations was performed on a Wild STK stereocomparator. Use of the stereocomparator allowed the operator to drill the pass point images down the center of each photograph only and to then stereoscopically transfer the drilled image to the overlapping photograph for measurement, without actually ever drilling the image on the second photograph. The stereocomparator measuring mark consisted of a 165-micron diameter black circle having a 20-micron black dot at its center. The dot was centered in the 60-micron diameter drilled pass point image when observing the photocordinates for the point.

FIDUCIAL MARKS

In the time interval occurring between the film exposure, its development, and the subsequent printing of the glass plate diapositive or transparency, the aerial film undergoes a random enlargement and shrinkage change. Since the accuracy of analytic photogrammetric computations depend on the use of a true central perspective, it is necessary to compensate for the film distortion and thereby mathematically return the film to the physical format present at the instant of exposure. This can be achieved by comparing the positions of the images created by the fiducial marks on each photograph with the true positions of these marks in the camera focal plane. The photograph is then mathematically stretched so as to place the fiducial marks back into their true positions.

In metric mapping cameras, the fiducial marks are located in the corners of the camera focal plane. Some cameras have additional fiducial marks at the midpoints of the sides of the focal plane. The marks are normally a part of the lens cone and thus remain in a fixed position relative to the camera lens. The intersection of the diagonals joining the corner fiducial marks should represent the principal point of the photograph, i.e., the foot of the perpendicular from the focal plane to the nodal point of the camera lens. The corner fiducial marks on the Wild aerial cameras owned by NOS consist of an interrupted cross having a 100-micron diameter dot at the center.

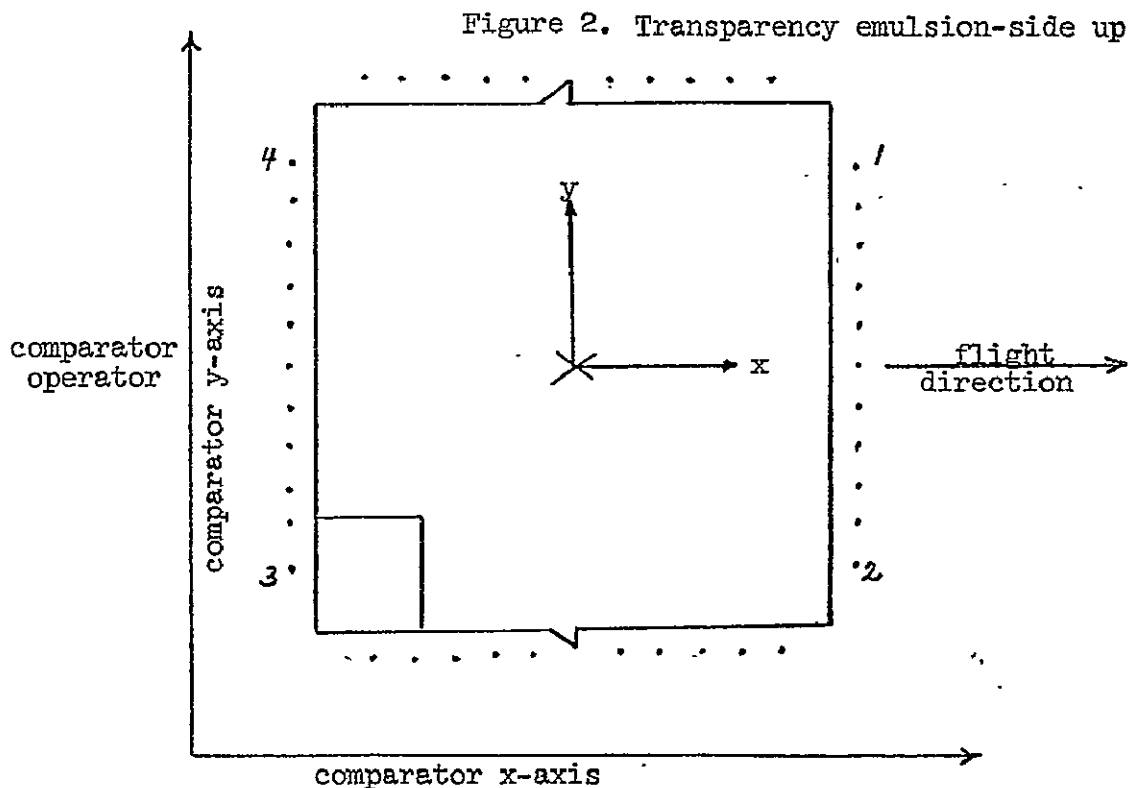


The ETC is not a metric camera in the photogrammetric sense because the fiducial marks and the image frame are a part of the removable film magazine and hence are not in a fixed position relative to the camera lens. Fortunately, the resulting lack of precision in locating the principal point on the photography is of minor consequence in narrow angle cameras, such as the ETC.

The ETC has a series of holes drilled around the perimeter of the image frame. These holes created photographic images having an approximate diameter of 330 microns. The images were of poor quality and rather ragged around the edges. For this reason, the stereocomparator operator centered the 165-micron circle of the measuring mark in the center of four holes selected to serve as fiducial marks.

NOS normally employs flash plates to provide a photographic record of the true relative positions of the camera fiducial marks. The flash plates are made in the laboratory by exposing a diapositive mounted in the camera so that its emulsion lies in the camera focal plane. Because the emulsion is secured on a stable glass base, the coordinates of the fiducial marks can be measured on a comparator later, with no concern for film shrinkage distortion.

Since no flash plate was available for the ETC, a nominal set of true fiducial coordinates was obtained by mounting each of the transparencies in turn on the comparator and then reading the photocordinates for the four selected fiducial holes on each of the photos. The data were entered into a flash-plate-reduction program to accomplish the following tasks: 1. Correct the observed photocordinates of the fiducial holes for comparator systematic errors, 2. determine by least square methods a meaned set of nominal true photocordinates for the fiducial holes in a coordinate system, having its origin at the principal point (intersection of diagonals joining fiducials 1-3 and 2-4) and oriented so that $x_3 \approx y_3 = y_2$. See Figure 2 below. As a consequence of this computation, the direction of flight becomes the x-axis of the photocoordinate system.



The meaned set of nominal true photocordinates for the fiducial holes provided by the flash-plate-reduction program are:

FIDUCIAL HOLE	x (microns)	y
1	59227.74	50154.18
2	59112.61	-50132.70
3	-59202.38	-50132.70
4	-59112.77	50132.84

The data were then prepared for processing through the NOAA/NOS analytic aerotriangulation system of computer programs. All of the computations were performed on the CDC 6600 computer.

COMPUTER PROCESSING

The 12-photo strip extended over the three states of South Carolina, North Carolina, and Virginia. The computational processing requires all of the ground positional data to be expressed in a common three-dimensional coordinate system. In order to attain this condition, and also to compensate for the presence of earth curvature in the data, the initial computation was to develop secant plane coordinates for each of the 29 office-identified control stations. Accordingly, the Geographic Positions and elevations of these points were processed through the Secant Plane Coordinate Transformation program.

Secant Plane Coordinate Transformation: The elevations of the control points obtained from the 1:24,000 scale USGS quadrangles and airport surveys are based on sea level and thus do not recognize the existence of earth curvature. The program computations begin with a conversion of the Geographic Positions and elevations to an orthogonal geocentric coordinate system having its origin at the center of the earth as defined by the Clarke 1866 Spheroid. The geocentric coordinates are then transformed into a secant plane coordinate system in which the secant plane intercepts the earth's surface near the edges of the area to be mapped so that most of the terrain objects will possess a positive Z (elevation) coordinate. The origin of the secant plane system is placed near the center of the project area. The secant plane origin selected for the SKYLAB study was Latitude $36^{\circ} 20' 00''$, Longitude $-78^{\circ} 45' 00''$. The Z-axis is the extension of the normal to the ellipsoid which, because of the earth's ellipsoidal nature, does not pass through the center of the earth. The X-axis points towards the East and the Y-axis points towards the North.

Table 4 shows the Geographic Position and elevation input to the program and the resulting secant plane coordinate output from this program.

CONVERSION OF CONTROL STATION GEOGRAPHIC POSITIONS
TO SECANT PLANE COORDINATES

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SECANT PLANE ORIGIN

LATITUDE 36 20 00 LONGITUDE -078 45 00

GEOGRAPHIC POSITION INPUT

			Elevation (feet)
288100	34 59 20.200	-080 57 18.000	650.0
288110	35 15 25.015	-081 01 37.254	710.0
288201	35 15 05.424	-081 01 43.630	633.0
288111	34 44 15.094	-080 40 58.811	565.000
288202	34 43 34.559	-080 42 15.428	598.0
288120	35 12 31.865	-080 57 00.375	707.0
288101	35 13 13.390	-080 56 18.073	740.00
290110	35 44 30.052	-080 21 43.729	760.00
290201	35 44 34.185	-080 21 48.169	753.0
290111	35 03 03.258	-079 50 57.400	456.0
291120	36 05 57.511	-079 57 09.510	926.0
291121	36 05 13.059	-079 56 15.037	900.0
292110	36 08 32.741	-079 47 26.181	843.0
292111	35 36 54.282	-079 02 53.990	185.0
293100	35 52 20.520	-078 47 01.000	430.00
293120	35 51 52.243	-078 47 51.245	398.0
293121	35 51 57.031	-078 46 49.346	401.0
293110	36 05 18.889	-079 03 46.083	516.00
294102	36 40 29.600	-079 00 53.200	530.00
295100	36 49 04.400	-077 54 11.700	350.00
296111	37 13 22.840	-077 59 24.112	322.00
296201	37 13 10.548	-077 59 37.971	339.0
296110	36 39 51.186	-077 34 17.309	156.0
297120	37 29 44.350	-077 18 25.908	161.0
297121	37 30 14.556	-077 18 38.599	160.0
298110	37 12 17.161	-076 59 13.914	112.0
299100	37 26 54.700	-076 42 42.100	10.00
299110	37 54 13.346	-076 51 44.738	031.0
299111	37 26 06.654	-076 20 11.559	013.0

SECANT PLANE OUTPUT IN METERS

	X	Y	Z
288100	-201278.692	-146855.736	-3874.837
288110	-207169.956	-116985.134	-3424.735
288201	-207344.107	-117584.396	-3464.941
288111	-176997.192	-175263.639	-3901.313
288202	-178969.743	-176473.122	-3979.759
288120	-200294.019	-122480.950	-3309.711
288101	-199196.924	-121226.254	-3241.238
290110	-145819.163	-64433.577	-962.699
290201	-145928.545	-64304.337	-966.024
290111	-100287.221	-141707.209	-1430.977
291120	-108297.906	-25295.089	110.910
291121	-106952.115	-26681.925	119.998
292110	-93656.711	-20679.874	333.841
292111	-27029.441	-79651.423	297.541
293100	-3035.511	-51147.971	721.944
293120	-4296.418	-52018.862	704.400
293121	-2743.370	-51871.929	707.371
293110	-28172.927	-27112.861	834.668
294102	-23669.361	37934.083	801.864
295100	75550.344	54100.713	226.922
296111	67448.740	98990.886	-231.394
296201	67110.169	98609.407	-216.716
296110	105357.883	37358.925	-134.052
297120	127578.566	129930.492	-1756.009
297121	127252.667	130856.770	-1768.812
298110	156468.136	98126.586	-1843.117
299100	180328.210	125649.347	-2988.252
299110	165981.068	175874.338	-3784.177
299111	213537.475	124932.816	-3997.981

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Image Coordinate Refinement and Three-Photo Orientation: The x and y photocoordinates observed on the stereocomparator for the fiducial and nonfiducial images on each transparency were then processed through the image coordinate refinement and three-photo orientation program. All of the photocoordinates were first corrected for comparator calibration errors. The program then performed a least squares fit of the fiducial hole photocoordinates to the nominal true photocoordinates for these fiducial holes, as previously obtained from the flash-plate-reduction program. This operation of placing the fiducial holes back into their true positions serves to correct all of the data for film shrinkage distortion and to express the photocoordinates in a two-dimensional photocoordinate system having its origin at the principal point and oriented so that the x -axis is the direction of flight.

The systematic errors still remaining in the photocoordinate data are those due to the distortions introduced by the aerial camera lens and atmospheric refraction. The Addendum to LEC/ASD Technical Memo No. TM 73-002 - April 1973 issued on July 11, 1974, indicated the camera lens symmetrical distortion and the asymmetrical distortion caused by lens decentration to be probably insignificant from zero. In addition, distortion due to atmospheric refraction at camera altitudes above 40 miles is relatively negligible. For this reason, no attempt was made during the image coordinate refinement phase to compensate for camera lens and atmospheric refraction distortion.

The refined image coordinates provided by the program theoretically should be nearly all free of systematic error and contain only residual observational discrepancies in them. These refined coordinates were then punched out to serve as input to the block adjustment program.

The program then proceeded to the three-photo camera orientation phase, which comprises an interrelated geometric fitting of the photographs, based only on the refined photocoordinates and is entirely independent from any ground control data. The computation is iterative and derives the orientation of each photograph relative to the previous two in the strip. It also determines the positions of all pertinent objects in a three-dimensional coordinate system at the scale of the photography. The collineation principle is imposed in a least squares solution that minimizes the residual observational discrepancies in the image coordinates. The residual discrepancies are analyzed by the computer, which discards those images exhibiting excessively large discrepancies. The removal of these blunders provides "clean" photocoordinate data for all subsequent computations.

Strip Adjustment to Ground Control: The analysis of three photographs at a time automates the joining of the separate triplets into a continuous strip and develops a set of model coordinates that are analogous to the product obtained from conventional stereotriangulation on stereoscopic plotting instruments. The horizontal and vertical strip adjustment transforms the model coordinate data into the prevailing ground control coordinate system, which is a secant plane coordinate system for this study, by fitting to the control stations through the application of polynomial equations and least squares. Any large residual discrepancies appearing in the resulting adjustment are corrected in order to obtain blunder-free provisional ground position data prior to entering the block adjustment computation.

The strip adjustment of the SKYLAB photography was performed holding to the 14 photo control stations identified on Figure 1 by a Δ . Note: These same 14 stations were employed later to control the block adjustment solution. The strip adjustment was performed twice--going from frame 86-288 to frame 86-299 and then going from frame 86-299 to frame 86-288. In both adjustments, the resulting discrepancies at the 14 held photo control stations and 15 withheld stations increased in magnitude from about 25 meters at the beginning of the strip to approximately 100 meters at the tail end of the bridge. Results of this nature do not occur on normal photogrammetric mapping operations conducted by NOS. The appearance of these apparently systematic strip adjustment discrepancies on the SKYLAB bridge is assumed to be attributable to the failure to completely compensate for the systematic errors introduced into the data by the nonmetric characteristics of the Earth Terrain Camera.

Block Adjustment: In order to maximize the accuracy of the analytic aerotriangulation, the block adjustment program was applied, using the previously obtained refined photocordinates and the provisional object coordinates. The program permits a simultaneous solution of the absolute orientation of all the photographs, together with a determination of the finalized coordinates for each object. This office has developed three simultaneous analytical aerotriangulation block adjustment programs for operation on the CDC 6600 computer.

1. 25-Photo Block Adjustment: This program was designed to service smaller organizations not having access to large-size computers and will accommodate blocks up to 25 photos in size. All input/output is on cards, and the program requires less than 50,000 words of computer core storage. The logic of the solution is similar to that of the 185-photo block adjustment program.

2. 185-Photo Block Adjustment: The block can contain as many as 185 photographs in a single simultaneous least squares solution. All input/output is on tape. Approximately one million words of storage are required, and therefore auxiliary disk storage and extended core storage is used to augment the CDC 6600 core memory.

The area to be block adjusted may be of any shape. The strips of photography can be of variable length and may have any overlap with other strips in the block. Thus, diagonal cross-flights may be included, if desired. The photographs can be entered into the solution in any order. Photographs taken by aerial cameras having different focal lengths may be used simultaneously in the solution.

All of the pass points and control stations contribute equations to the normal equation matrix and thus influence the least squares orientation solution. Corrections to the provisional coordinates for these objects are computed simultaneously with the determination of the absolute orientation of all the photographs in the block. The unweighted control stations perform as if they are pass points. The weighted control stations can be computed as if they are pass points by using their refined photocoordinates and the finalized camera parameters from the orientation solution to determine their ground coordinates by intersection.

3. 600-Photo Block Adjustment: Blocks up to 600 photographs in size can be accommodated in this version. All input/output is on tape. Auxiliary disk storage is necessary because the program requires nearly one million words of memory.

This version is not as flexible as the 185-photo program in terms of data input organization, but the arithmetic approach employed results in a more efficient computation and a much shorter computer running time. The area should be square or rectangular in order to simplify the arrangement of input data. Photographs must be entered into the solution in the exact order in which they were taken and may not overlap each other by more than 60 percent. No strip can have more than 20 pictures in it. The program permits the mixing of photographs taken by aerial cameras of different focal lengths.

All of the pass points and control stations contribute equations to the normal equation matrix and thus influence the least squares orientation solution. The finalized camera parameters from the orientation solution and the refined photocoordinates of the pass points and control stations are used to compute the final ground coordinates for these objects by intersection.

The 600-photo block adjustment program was used for the SKYLAB analytic aerotriangulation study. A Fortran listing of this program is given in Appendix B.

Thirty-six pass points (one in each relative orientation location) and all of the 29 office-identified photo control stations were permitted to contribute observation equations to the normal equation matrix and thereby influence the least squares orientation solution of the 12 photographs comprising the block. The provisional coordinates for these objects should be reasonably close to their true values in order to minimize the number of iterations required of the block adjustment solution. For this reason, the initial ground (secant plane) coordinates of the pass points consisted of the data furnished by the first half of the strip adjustment going from frame 86-288 to frame 86-299--and by the first half of the strip adjustment going from frame 86-299 to frame 86-288. The known true ground (secant plane) coordinates were used as the initial coordinates for the 29 photo control points.

Table 5 is a listing of the initial provisional ground (secant plane) coordinates for the pass points and the photo control stations. A listing of the refined photocoordinates for these pass points and photo control stations, as previously punched out by the Image Coordinate Refinement and Three-Photo Orientation program, is given in Table 6.

292
292291310 -4.8126509E-02 -3.0527771E-02
292291320 -5.2868542E-02 4.7874533E-02
292291330 -5.1129797E-02 3.5506342E-03
292292310 1.8499420E-03 -3.0333683E-02
292292320 4.0858396E-03 4.8972518E-02
292292330 -9.3830666E-04 7.8532402E-03
292293310 5.1925419E-02 -2.8029944E-02
292293320 5.0031725E-02 5.0058976E-02
292293330 4.7535343E-02 4.5751374E-03
292292110 -1.9237138E-02 4.3086281E-02
292291120 -3.4734189E-02 4.8658235E-02
292291121 -3.4488084E-02 4.6586076E-02
292293100 3.8201346E-02 -4.1701161E-02
292293110 3.2417993E-02 -4.9433929E-03
292293120 3.6554509E-02 -4.1634943E-02
292293121 3.7984083E-02 -4.2517091E-02
292292111 -7.2191183E-04 -5.0470942E-02
293
293292310 -4.6876203E-02 -3.1929435E-02
293292320 -4.4675254E-02 4.7409829E-02
293292330 -4.9701058E-02 6.2704290E-03
293293310 3.2954850E-03 -2.9647102E-02
293293320 1.3644901E-03 4.8547058E-02
293293330 -1.1609361E-03 3.0063077E-03
293294310 4.9291420E-02 -2.6523827E-02
293294320 5.0331744E-02 3.7760516E-02
293294330 5.0443036E-02 4.6554986E-03
293293100 -1.0472546E-02 -4.3320930E-02
293293110 -1.6304848E-02 -6.5265715E-03
293293120 -1.2119203E-02 -4.3255058E-02
293293121 -1.0684280E-02 -4.4135354E-02
293294102 2.9769123E-02 4.6062768E-02
294
294293310 -4.5408740E-02 -3.1276435E-02
294293320 -4.7413524E-02 4.6910495E-02
294293330 -4.9922832E-02 1.3757361E-03
294294310 6.4136652E-04 -2.8164236E-02
294294320 1.6050855E-03 3.6179394E-02
294294330 1.7489357E-03 3.0448055E-03
294295310 4.8336748E-02 -2.7948864E-02
294295320 4.5921897E-02 3.1223507E-02
294294102 -1.9005334E-02 4.4462580E-02
294295330 5.0752810E-02 7.0171463E-03
295
295294310 -4.8065487E-02 -2.9755754E-02
295294320 -4.7116111E-02 3.4612072E-02
295294330 -4.6971411E-02 1.4643224E-03
295295310 -2.8582516E-04 -2.9563473E-02
295295320 -2.7288240E-03 2.9684546E-02
295295330 2.1121530E-03 5.4490202E-03
295296310 4.8350200E-02 -3.0367873E-02
295296320 4.8859741E-02 4.8204153E-02
295296330 4.3942351E-02 9.7309548E-03
295296110 4.1888299E-02 -4.1150655E-02
295296111 4.9557802E-02 3.5889388E-02
295295100 2.7383244E-02 -7.6541133E-03
295296201 4.9025404E-02 3.5791637E-02
296
296295310 -4.8912550E-02 -3.1175464E-02
296295320 -5.1417141E-02 2.8070525E-02
296295330 -4.6558160E-02 3.8367575E-03
296296310 -2.1747625E-04 -3.2005718E-02
296296320 2.4754045E-04 4.6660238E-02
296296330 -4.6724768E-03 8.1401176E-03
296297310 5.1814312E-02 -2.1334985E-02
296297320 5.1438535E-02 4.2232885E-02
296297330 4.9087131E-02 5.1457554E-03
296296110 -6.6781630E-03 -4.2801992E-02
296296111 9.5107825E-04 3.4330292E-02
296295100 -2.1251919E-02 -9.2674902E-03
296296201 4.1528880E-04 3.4232754E-02

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297		
297296310	-4.8884683E-02	-3.3540838E-02
297296320	-4.8471439E-02	4.5150300E-02
297296330	-5.3387673E-02	6.6214000E-03
297297310	3.2292043E-03	-2.2914424E-02
297297320	2.8155666E-03	4.0743480E-02
297297330	4.7887551E-04	3.6049954E-03
297298310	4.9384170E-02	-3.1794614E-02
297298320	4.8950281E-02	4.5322814E-02
297298330	5.3156090E-02	1.1645544E-02
297296111	-4.7770507E-02	3.2823481E-02
297297120	2.3627514E-02	2.0265087E-02
297297121	2.3945413E-02	2.1263032E-02
297298110	2.7641953E-02	-2.5576312E-02
297296201	-4.8307759E-02	3.2723607E-02
298		
298297310	-4.5428380E-02	-2.4470411E-02
298297320	-4.5919888E-02	3.9161207E-02
298297330	-4.8222649E-02	2.0387070E-03
298298310	8.0468845E-04	-3.3377516E-02
298298320	2.9431491E-04	4.3796670E-02
298298330	4.5390987E-03	1.0100176E-02
298299310	4.7350772E-02	-5.1665726E-02
298299320	4.4515357E-02	4.8243494E-02
298299330	5.1835518E-02	1.2330690E-02
298299110	3.7430048E-02	3.3063014E-02
298297120	-2.5071781E-02	1.8706945E-02
298297121	-2.4755306E-02	1.9706280E-02
298298110	-2.0994424E-02	-2.7139170E-02
298299100	1.7160147E-02	-1.9058386E-02
298299111	4.4993911E-02	-4.1062900E-02
299		
1 1		
299298310	-4.7827856E-02	-3.4851692E-02
299298320	-4.8340167E-02	4.2357455E-02
299298330	-4.4103047E-02	8.6372888E-03
299299310	-1.1510283E-03	-5.3232239E-02
299299320	-4.0500174E-03	4.6813308E-02
299299330	3.2847107E-03	1.0854518E-02
299000301	-1.9679956E-10	-3.8623708E-09
299000302	-1.9679956E-10	-3.8623708E-09
299000303	-1.9679956E-10	-3.8623708E-09
299299110	-1.1156657E-02	3.1610337E-02
299299100	-3.1453155E-02	-2.0549835E-02
299299111	-3.5411964E-03	-4.2610240E-02

End of Table 6.

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Weighting the Block Adjustment Solution: The weighting of the block adjustment solution is performed by applying image quality and control station weights to the data during the computations. These weights can be defined as follows:

Image Quality Weights: It is logical to weight a block adjustment in favor of those observation equations provided by the better quality images because their equations are more reliable. Image quality is primarily influenced by lens resolution and the type of ground object creating the image. The weighting is accomplished by multiplying each observation equation by a number expressing its relative reliability.

Control Station Weights: The observation equations are written for each image on every photograph in the block created by the pass points, control stations, and other objects which are used to influence the least square orientation solution. When written for image created by the control stations, it is necessary to recognize that their initial provisional X, Y, Z ground coordinates were obtained by classical ground surveying methods and should be favored during the block adjustment. This is accomplished by increasing the size of the main diagonal elements of the normal equation matrix, which are the coefficients of the unknown dX , dY , and/or dZ correction terms. This serves to reduce the size of the unknown dX , dY , and/or dZ correction terms when the normal equations are solved. By reducing the magnitude of the corrections to the initial approximations, the least square adjustment is constrained in favor of these initial values. Control stations that are not subjected to this type of weighting perform as pass points. These unweighted or withheld control stations provide a means for evaluating the accuracy of the block adjustment solution.

Presently, empirical values are used for these weights at NOS instead of being based on the standard error of the observations as required by rigorous statistical methods. Also, the present NOS block adjustment program multiplies the pertinent normal equation main diagonal terms by the control station weights instead of adding on a number to increase their size.

The resulting accuracy of the block adjustment can be expressed as a photogrammetric RMS error and a geodetic RMS error. The photogrammetric RMS error is computed using the residual v_x and v_y plate observational discrepancies of all images contributing observation equations to the orientation solution. The geodetic RMS error reflects a comparison of the X, Y, Z results of the block adjustment computation with the known X, Y, Z coordinates for the control stations that were obtained by classical ground surveying methods. In most NOS operations, weights are selected that cause the photogrammetric RMS error and the geodetic RMS error to be about equal. This has the effect of providing for an equal distribution of the block adjustment errors between the photogrammetric observations and the geodetic field observations.

The inherent errors in using nonmetric S-190B photography and office-identified photo control made it necessary to perform numerous block adjustment solutions involving different combinations of control and weights. The best results were achieved by using 14 weighted control stations distributed uniformly along the perimeter of the strip as shown in Figure 1. In NOS mapping operations using metric photography and field-identified photo control, eight weighted photo control stations would normally have been sufficient for a block adjustment of the 12 photos.

As previously noted, the pass points were drill holes in the emulsion and not images of specific terrain objects. The stereo-comparator operator cannot remove parallax exactly on the drilled pass point holes when observing their photocordinates. This reduces the reliability of the pass point images during the photo-coordinate measurement process. The office-identified photo control stations, on the other hand, were prominent ground features providing sharp images on the overlapping photographs. Since drilling was not necessary for these stations, the comparator operator was able to remove parallax directly at the images before observing their photocordinates. As a consequence of their higher reliability, a larger image quality weight was assigned to the control station images.

Many combinations of image quality and control station weights were applied to the 14 held photo control stations in an effort to optimize the accuracy of the block adjustment solution. In general all of these weight combinations yielded a horizontal position geodetic RMS error of approximately 15 meters for the 15 withheld (unweighted) photo control points. The maximum horizontal position error on any withheld control station was less than 26 meters.

Results of the Block Adjustment Solution: The weights used for each of the 14 held photo control stations in the final block adjustment of the SKYLAB data were: image quality weight = 6; control station weight for X and Y = 6; control station weight for Z = 3. A smaller weight was used for Z because of the limited accuracy in the stereo height determination resulting from the low base-height of 0.10, even though the known elevations of the control stations were of a higher accuracy than the known horizontal positions for these stations (see Table 3). In fact, a higher Z weight was found to degrade the block adjustment accuracy.

The pertinent output from the 600-photo block adjustment program for the SKYLAB study is shown in Table 7. A summary of the residual errors remaining at each of the 29 control stations is given in Table 8. All of the ground coordinate data and the residual errors are in meters and expressed in the secant plane coordinate system. The results presented here are from a block adjustment solution in which the standard error of the ground control was assumed to be 4.1 meters. The residual errors given in Table 8 are also shown on Figure 1 in red.

Table 7. Output from 600-photo block adjustment program

SKYLAB COL.MTS.-6 POS.MTS. XY-Z-3

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001

POSITION WEIGHT VARIES

FL-CONSTANT = $4.574110E+00$ MAXIMUM ITERATIONS = 9 RESIDUAL LIMIT (MICRONS) = $2.500000E+02$
RESOLUTION HEIGHTS W1712 = $1.000000E+01$ W172P = $1.000000E+01$

CONTROL EQUATION XY Z (0=NO CONSTRAINT)

288110	6	6	3
288111	6	6	3
290110	6	6	3
290111	6	6	3
292110	6	6	3
292111	6	6	3
293120	6	6	3
294102	6	6	3
296110	6	6	3
296111	6	6	3
297120	6	6	3
298110	6	6	3
299110	6	6	3
299111	6	6	3

BLOCK CONTAINS 12 PHOTOGRAPHS AND 65 OBJECTS

PROGRAM PASS 1 LAST-PLATE-DZO IS $3.014291E-04$ DIVIDED BY $5.9386125E-01$
PROGRAM PASS 1 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF $1.001832E-04$ FOR PLATE 293

PROGRAM PASS 2 LAST PLATE DZO IS $9.836330E-06$ DIVIDED BY $5.717103E-01$

PROGRAM-PASS-2-PRODUCES A MAXIMUM ORIENTATION CORRECTION OF $1.988614E-03$ FOR PLATE 289

PROGRAM PASS-3-LAST-PLATE-DZO IS $1.579917E-07$ DIVIDED BY $5.788628E-01$

PROGRAM PASS 3 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF $1.332512E-03$ FOR PLATE 296

PROGRAM PASS 4 LAST PLATE DZO IS $4.289872E-08$ DIVIDED BY $5.787685E-01$

PROGRAM-PASS-4-PRODUCES A MAXIMUM ORIENTATION CORRECTION OF $3.600510E-04$ FOR PLATE 296

PROGRAM PASS-5-LAST PLATE DZO IS $3.798155E-09$ DIVIDED BY $5.787877E-01$

PROGRAM PASS 5 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF $7.313948E-05$ FOR PLATE 296

PLATE XO YO ZO

288	-212568.644	-167262.112	421918.350
289	-17067.096	-136730.888	423734.499
290	-13624.582	-107054.703	420030.943
291	-99018.272	-73428.440	426552.677
292	-62503.728	-47235.109	427155.800
293	-22395.898	-13119.062	427359.469
294	13053.497	13951.402	427610.488
295	48517.492	49291.909	427663.759
296	80092.865	76459.516	426677.202
297	126788.565	111151.412	425600.806
298	161820.156	130657.700	424551.076
299	199498.185	168641.092	422504.008

PLATE OMEGA PHI KAPPA

288 $1.246236E-01$ $9.992222E+00$ $3.925313E-01$

289 $1.794904E+00$ $6.067400E+00$

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287	.2056309E-01	-.3374707E-01	.6004401E+00
289	.9997086E+00	.9994304E+00	.7951204E+00
290	.1830683E-01	-.2509980E-01	.6062359E+00
290	.9998324E+00	.9996850E+00	.7952049E+00
291	.6856848E-02	-.2193608E-01	.6059955E+00
291	.9999765E+00	.9997594E+00	.7954561E+00
292	.1281470E-01	-.1641826E-01	.6059890E+00
292	.9999179E+00	.9998304E+00	.7954730E+00
293	.1431633E-03	-.6218802E-02	.6056331E+00
293	.1000000E+01	.9999807E+00	.7957440E+00
294	.3912340E-02	-.5802441E-02	.6046630E+00
294	.9999923E+00	.9999032E+00	.7964814E+00
295	-.1163633E-01	-.5493705E-02	.6047695E+00
295	.9999323E+00	.9999849E+00	.7964005E+00
296	-.1287806E-01	.1796298E-02	.6051827E+00
295	.9999171E+00	.9999984E+00	.7960807E+00
297	-.2250270E-01	.1243014E-01	.6048853E+00
297	.9997468E+00	.9999221E+00	.7963126E+00
298	-.2001792E-01	.1181439E-01	.6041539E+00
298	.9997996E+00	.9999302E+00	.7968577E+00
299	-.2335977E-01	.1497957E-01	.6046433E+00
299	.9997271E+00	.9998878E+00	.7964904E+00

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INTERSECTION OF OBJECTS USED IN SOLUTION ***
(SCANT PLATE COORDINATES - MICRONS)

OBJECT X GROUND Y GROUND Z GROUND IMAGE VX PLATE RESID VY PLATE RESID

286310	-175159.941	-176554.007	-3763.068	286288.10	RMS OBJECT =	.3232136E+01 MICRONS	4.569	-149	147	-47568
286320	-22+533.782	-118960.309	-4350.547	286288.20	RMS OBJECT =	.00+2039E+00 MICRONS	1.137	-035	016	-1.137
286330	-196938.725	-154397.051	-3873.622	286288.30	RMS OBJECT =	.2760765E+01 MICRONS	3.903	-124	125	-3.902
289310	-140966.327	-150574.857	-2564.325	286288.10	RMS OBJECT =	.1753481E+02 MICRONS	31.507	7.206	-13.376	-14.702
				289289.310			8.169			-16.760
289320	-186866.970	-95485.277	-2601.182	286289.320	RMS OBJECT =	.185560+E+02 MICRONS	27.815	-6.882	12.799	4.276
				289289.320			5.876			-32.067
289330	-163941.845	-124266.507	-2443.418	286289.330	RMS OBJECT =	.1773059E+02 MICRONS	30.417	-528	045	612
				289289.330			501			30.986
286110T	-207169.956	-116985.134	-3424.735	286288.110	RMS OBJECT =	.3009886E+01 MICRONS	4.254	-133	136	-4.254
286110	-207159.931	-116964.805	-3657.839	286288.110						
286111T	-176997.192	-175263.639	-3901.313	286288.111	RMS OBJECT =	.3865919E+01 MICRONS	5.465	-178	176	-5.464
286111	-177004.709	-175269.251	-3729.028	286288.111						
286201	-207333.116	-117576.663	-3601.537	286288.201	RMS OBJECT =	.2193668E+01 MICRONS	3.101	-097	099	-3.100
				286288.201						

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△ 288100	-201278.692	-146855.736	-3874.837	288288100	-0.098	3.089
	-201266.954	-146866.219	-3505.180	289288100	.009	-3.988
	11.738	-12.483	-30.343			
				RMS OBJECT=	.216507E+01 MICRONS	
△ 288101	-199196.924	-121226.254	-3241.238	288288101	-.210	6.668
	-199181.903	-121207.223	-3451.964	289288101	.214	-6.664
	14.961	19.031	-210.726			
				RMS OBJECT=	.4716035E+01 MICRONS	
△ 288120	-200294.019	-122480.950	-3309.711	288288120	-.193	6.145
	-200279.641	-122471.264	-3515.693	289288120	.197	-6.142
	14.378	9.686	-205.982			
				RMS OBJECT=	.346124E+01 MICRONS	
△ 288202	-178969.743	-176473.122	-3979.759	288288202	-.111	3.422
	-178980.461	-176476.017	-3845.203	289288202	.110	-3.421
	-10.718	-2.895	134.556			
				RMS OBJECT=	.2420584E+01 MICRONS	
290310	-106548.354	-122833.069	-1039.850	289290310	-8.448	29.712
				290290310	12.090	19.283
				291290310	-7.719	-49.040
				RMS OBJECT=	.2046531E+02 MICRONS	
290320	-152383.610	-63563.072	-1164.540	289290320	.067	12.399
				290290320	-.787	-5.157
				291290320	.741	-7.230
				RMS OBJECT=	.6241998E+01 MICRONS	
290330	-131685.875	-96569.496	-899.691	289290330	-2.367	17.608
				290290330	3.381	-7.500
				291290330	-1.015	-14.040
				RMS OBJECT=	.9468433E+01 MICRONS	
△ 290110T	-145819.163	-64433.577	-962.699	289290110	-.716	11.743
△ 290110	-145821.193	-64426.763	-950.963	290290110	.899	-5.985
	-2.030	6.814	11.736	291290110	-.169	-5.746
				RMS OBJECT=	.5889054E+01 MICRONS	
△ 290111T	-100287.221	-141707.209	-1430.977	289290111	-.006	2.551
△ 290111	-100286.078	-141713.583	-1517.218	290290111	.005	-2.545
	1.143	-6.379	-86.241			
				RMS OBJECT=	.1801733E+01 MICRONS	
△ 290201	-145928.545	-64304.337	-966.024	289290201	-.185	14.294
	-145925.244	-64306.415	-925.436	290290201	-.377	-6.522
	3.301	-2.078	40.588	291290201	.543	-7.757
				RMS OBJECT=	.7190405E+01 MICRONS	

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291310	-73506.450	-91026.878	-029.069	290291310	-9.747	49.531
				291291310	15.778	-34.368
				292291310	-0.050	-15.182
				RMS OBJECT=	.2060057E+02 MICRONS	

291320	-121335.359	-30081.667	-44.274	290291320	-2.976	34.124
				291291320	4.270	13.212
				292291320	-1.259	-7.310
				RMS OBJECT=	.2451515E+02 MICRONS	

291330	-94988.940	-67908.199	-315.295	290291330	-5.054	33.280
				291291330	9.535	1.613
				292291330	-3.871	-34.861
				RMS OBJECT=	.2026214E+02 MICRONS	

292310	-36515.376	-63241.457	449.438	291292310	.006	20.003
				292292310	-.647	.606
				293292310	.566	-20.573
				RMS OBJECT=	.1172226E+02 MICRONS	

292320	-79693.386	-3100.307	295.041	291292320	-1.101	-15.172
				292292320	1.278	22.173
				293292320	-.163	-6.983
				RMS OBJECT=	.1135391E+02 MICRONS	

292330	-60177.549	-36467.791	522.021	291292330	1.456	14.859
				292292330	-2.595	-.601
				293292330	1.552	-14.244
				RMS OBJECT=	.8539582E+01 MICRONS	

292110T	-93656.711	-20679.874	333.841	291292110	.016	.505
292110	-93657.861	-20673.281	295.369	292292110	-.016	-.505
	-1.150	6.593	-38.472	RMS OBJECT=	.3072315E+00 MICRONS	

291120	-108297.906	-25295.089	110.910	291291120	.373	11.762
	-108298.113	-25288.198	32.891	292291120	-.373	-11.768
	-0.207	6.891	-78.019	RMS OBJECT=	.8723276E+01 MICRONS	

291121	-106952.115	-26681.925	119.998	291291121	.376	11.855
	-106939.471	-26688.740	94.186	292291121	-.376	-11.860
	12.644	-6.815	-25.212	RMS OBJECT=	.8380516E+01 MICRONS	

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292111T	-27029.441	-74051.423	297.541	291292111	.029	.958
292111	-27020.950	-79654.702	292.103	292292111	-.029	-.956
	0.491	-3.279	-5.378			
				RMS OBJECT=	.6772417E+00 MICRONS	

293310	-557.116	-33201.994	680.547	292293310	-2.875	2.925
				293293310	6.135	-1.587
				294293310	-3.271	-.437
				RMS OBJECT=	.3456629E+01 MICRONS	

293320	-46155.211	23748.689	755.439	292293320	-.172	54.404
				293293320	-2.677	-25.514
				294293320	2.998	-26.753
				RMS OBJECT=	.2724478E+02 MICRONS	

293330	-22306.105	-11480.964	1059.436	292293330	-.748	15.156
				293293330	.735	-5.187
				294293330	.030	-9.936
				RMS OBJECT=	.7707338E+01 MICRONS	

△ 293100	-3035.511	-51147.971	721.944	292293100	.021	-.421
	-3040.499	-51135.036	747.140	293293100	-.021	.421
	-4.988	12.935	25.196			
				RMS OBJECT=	.2980114E+00 MICRONS	

△ 293110	-28172.927	-27112.861	834.668	292293110	-.352	7.091
	-28159.653	-27103.185	821.656	293293110	.352	-7.080
	13.274	9.672	-13.012			
				RMS OBJECT=	.5016334E+01 MICRONS	

△ 293120T	-4296.418	-52018.862	754.400	292293120	-.045	.965
293120	-4299.309	-52016.958	701.227	293293120	.048	-.963
	-2.891	-0.096	-3.773			
				RMS OBJECT=	.6824631E+00 MICRONS	

△ 293121	-2743.370	-51871.929	707.371	292293121	.070	-1.385
	-2734.791	-51864.213	701.808	293293121	-.066	1.383
	8.579	7.771	-5.563			
				RMS OBJECT=	.9797026E+00 MICRONS	

294310	31898.162	-4934.554	690.663	293294310	2.128	53.277
				294294310	-8.526	-20.876
				295294310	0.451	-32.427
				RMS OBJECT=	.2721705E+02 MICRONS	

294320	-3694.629	43458.533	304.189	293294320	8.376	6.996
				294294320	-17.479	2.727
				295294320	9.112	-11.708
				RMS OBJECT=	.1066998E+02 MICRONS	

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294330	15111.681	18897.43	550.016	293294330	6.616	27.264
				294294330	-13.415	-21.197
				295294330	6.834	-0.072
				RMS OBJECT=	.1581093E+02 MICRONS	
294102T	-23669.361	37934.083	801.864	293294102	.002	-.991
294102	-23668.327	37935.490	804.347	294294102	-.003	-.992
	1.034	1.407	2.332	RMS OBJECT=	.7012228E+00 MICRONS	
295310	67366.805	22135.331	82.479	294295310	-4.769	11.168
				295295310	8.057	4.448
				296295310	-3.318	-15.607
				RMS OBJECT=	.9006337E+01 MICRONS	
295320	32090.883	64818.444	330.914	294295320	-5.995	16.715
				295295320	9.789	20.451
				296295320	-3.809	-37.119
				RMS OBJECT=	.1924273E+02 MICRONS	
295330	49365.290	49544.761	285.874	294295330	-3.958	-.723
				295295330	7.263	23.505
				296295330	-3.726	-22.823
				RMS OBJECT=	.1387773E+02 MICRONS	
296310	104040.087	49038.235	87.815	295296310	-8.669	16.930
				296296310	15.334	18.665
				297296310	-0.736	-35.192
				RMS OBJECT=	.1921706E+02 MICRONS	
296320	59972.357	107751.460	-348.662	295296320	1.360	-3.643
				296296320	-2.938	1.108
				297296320	1.177	2.534
				RMS OBJECT=	.2258041E+01 MICRONS	
296330	78054.828	76365.232	94.902	295296330	-5.947	11.749
				296296330	10.993	1.040
				297296330	-5.066	-12.787
				RMS OBJECT=	.8966062E+01 MICRONS	
296110T	105357.883	37358.925	-134.052	295296110	.001	-.525
296110	105353.664	37357.931	-104.927	296296110	-.000	.524
	-4.219	-0.994	29.125	RMS OBJECT=	.3708215E+00 MICRONS	
296111T	67448.740	98930.886	-231.304	295296111	-1.157	1.018
296111	67450.678	98931.786	-238.805	296296111	2.237	-1.125
	1.938	0.900	-7.411	297296111	-1.084	.108
				RMS OBJECT=	.1260024E+01 MICRONS	

△ 295100	75550.344	54100.713	226.922	295295100	-0.014	11.393
	75565.486	54087.760	156.211	296295100	.006	-11.380
	15.142	-12.953	-70.711		RMS OBJECT=	.0051476E+01 MICRONS

△ 296201	67110.169	98609.407	-216.716	295296201	-1.162	1.325
	67109.161	98615.567	-213.343	296296201	2.214	-.540
	-1.008	6.180	3.373	297296201	-1.055	-.785
					RMS OBJECT=	.1292936E+01 MICRONS

297310	136781.254	66393.340	-1159.746	296297310	-.447	45.129
				297297310	-1.213	-35.761
				298297310	1.657	-9.311
					RMS OBJECT=	.2382777E+02 MICRONS

297320	100539.722	133424.765	-1563.397	296297320	-3.332	52.275
				297297320	4.436	-17.994
				298297320	-.996	-34.204
					RMS OBJECT=	.2664000E+02 MICRONS

297330	119761.767	104510.673	-1230.994	296297330	-3.241	44.673
				297297330	4.742	-26.403
				298297330	-1.460	-18.152
					RMS OBJECT=	.2258530E+02 MICRONS

298310	176204.799	105752.504	-2617.263	297298310	1.402	21.888
				298298310	-3.035	-22.784
				299298310	1.650	.901
					RMS OBJECT=	.1299309E+02 MICRONS

298320	132263.976	162905.948	-3090.611	297298320	-5.011	.412
				298298320	11.380	7.328
				299298320	-5.366	-7.722
					RMS OBJECT=	.7163833E+01 MICRONS

298330	154437.310	140222.139	-2944.173	297298330	-5.729	12.990
				298298330	10.638	-5.391
				299298330	-3.858	-7.582
					RMS OBJECT=	.0418980E+01 MICRONS

△ 297120T	127578.566	129930.492	-1756.009	297297120	-.005	3.226
297120	127581.797	129937.544	-1893.776	298297120	.058	-3.226
	3.231	7.052	-137.767		RMS OBJECT=	.2201002E+01 MICRONS

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△ 297121	127252.667	130856.770	-1768.812	297297121	-.046	2.700
	127254.334	130858.812	-1904.261	298297121	.048	-2.700
	1.667	2.042	-135.449	RMS OBJECT=	.1909497E+01	MICRONS
△ 298110T	156468.136	98126.586	-1843.117	297298110	-.033	1.924
298110	156462.106	98122.969	-1757.118	298298110	.035	-1.923
	-6.028	-3.617	85.999	RMS OBJECT=	.1366382E+01	MICRONS
299310	221333.928	118339.172	-4299.205	298299310	-.124	3.263
				299299310	.120	-3.259
				RMS OBJECT=	.2307715E+01	MICRONS
299320	162683.562	191183.725	-4075.060	298299320	-.113	3.209
				299299320	.112	-3.204
				RMS OBJECT=	.2208708E+01	MICRONS
299330	188418.605	160589.801	-4134.662	298299330	.059	-1.637
				299299330	-.058	1.634
				RMS OBJECT=	.1157261E+01	MICRONS
△ 299110T	165981.068	175874.338	-3784.177	298299110	-.135	3.812
299110	165977.778	175878.308	-3777.908	299299110	.134	-3.807
	-3.290	3.970	6.269	RMS OBJECT=	.2695222E+01	MICRONS
△ 299100	180328.210	125649.347	-2988.252	298299100	.120	-3.276
	180311.924	125630.652	-3126.692	299299100	-.118	3.272
	-16.286	-18.695	-138.440	RMS OBJECT=	.2516688E+01	MICRONS
△ 299111T	213537.475	124932.816	-3997.981	298299111	-.031	.639
299111	213537.179	124931.293	-4024.813	299299111	.031	-.838
	-0.296	-1.523	-26.832	RMS OBJECT=	.5935784E+00	MICRONS
RMS RESIDUAL FOR ENTIRE BLOCK = .1299550E+02 MICRONS						

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On all control: $RMS_x = \sqrt{\frac{2000.481761}{29}} = 8.306 \text{ m}$ $RMS_y = \sqrt{\frac{2328.910553}{29}} = 8.961 \text{ m}$ $RMS_{xy} = 12.218 \text{ meters on ground}$

On withheld control: $RMS_x = \sqrt{\frac{1747.814214}{15}} = 10.794 \text{ m}$ $RMS_y = \sqrt{\frac{1658.125318}{15}} = 10.514 \text{ m}$ $RMS_{xy} = 15.068 \text{ meters on ground}$

Note: 12.218 meters on ground = 12.915 microns @ plate scale

PLATE RMS (MICRONS)

288	.1072343E+02
289	.8281893E+01
290	.1812815E+02
291	.1368011E+02
292	.1512409E+02
293	.1307805E+02
294	.1198391E+02
295	.1122428E+02
296	.1543699E+02
297	.1277646E+02
298	.9159346E+01
299	.3319604E+01

End of Table 7.

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PHOTO CONTROL

STATION	X	Y	Z
△ 288100	11.738	-12.483	-30.343
▲ 288110	10.025	20.329	-233.104
△ 288201	10.991	7.727	-196.716
▲ 288111	-7.517	-5.612	172.285
△ 288202	-10.718	-2.895	134.556
△ 288120	14.378	9.686	-205.982
△ 288101	14.961	19.031	-210.726
▲ 290110	-2.030	6.814	11.736
△ 290201	3.301	-2.078	40.588
▲ 290111	1.143	-6.379	-86.241
△ 291120	-0.207	6.891	-78.019
△ 291121	12.644	-6.815	-25.212
▲ 292110	-1.150	6.593	-38.472
▲ 292111	0.491	-3.279	-5.378
△ 293100	-4.988	12.935	25.196
▲ 293120	-2.891	-0.096	-3.173
△ 293121	8.579	7.711	-5.563
△ 293110	13.274	9.672	-13.012
▲ 294102	1.034	1.407	2.332
△ 295100	15.142	-12.953	-70.711
▲ 296111	1.938	0.900	-7.411
△ 296201	-1.008	6.180	3.373
▲ 296110	-4.219	-0.994	29.125
▲ 297120	3.231	7.052	-137.767
△ 297121	1.667	2.042	-135.449
▲ 298110	-6.028	-3.617	85.999
△ 299100	-16.286	-18.695	-138.440
▲ 299110	-3.290	3.970	6.269
▲ 299111	0.296	-1.523	-26.832

Note: ▲ = weighted photo control station
 △ = unweighted photo control station

Table 8. Residual errors in meters remaining at each of the computed positions for the 29 office-identified photo control stations after block adjustment solution, as expressed in the secant plane coordinate system.

The block adjustment program is designed to terminate the iterative computation when the computed corrections to all of the angular camera parameters are each less than 0.00001 radians (two arc-seconds). Table 7 shows that five iterations of the block adjustment orientation solution were required to achieve this

condition for the SKYLAB study. Usually, only one such pass through the solution is necessary in conventional NOS mapping projects employing metric photography and field-identified photo control.

The residual errors at the control stations appear to be uniformly distributed throughout the test area, and there is no evidence that the least square solution was not able to absorb uncompensated systematic error, i.e., no large isolated discrepancies exist in the solution. The horizontal position geodetic RMS error for the 29 photo control stations was 12.218 meters and is equivalent to 12.915 microns at the SKYLAB photography scale of 1:946,000. The geodetic RMS error computed for only the 15 withheld photo control stations was 15.068 meters. The maximum horizontal position error was 24.794 meters and occurred at withheld station No. 299100. No serious attempt was made to hold closely to the elevations of the control stations because of the inherent limited accuracy in the stereo height determination. Consequently, several of the residual errors in Z exceeded -200 meters.

The photogrammetric RMS error was 12.996 microns at plate scale and was computed using the residual v_x and v_y plate discrepancies of all the images created on the photography by the 36 pass points and the 29 photo control stations. It should be noted that the photogrammetric RMS error is usually about eight microns on conventional NOS photogrammetric mapping projects.

Inverse of the Secant Plane Coordinate Transformation: After completion of the block adjustment solution, the adjusted computed secant plane coordinates were transformed back into the original ground coordinate system (Geographic Positions and elevations based on sea level) by applying the secant plane transformation in its inverse mode. The results of this inverse computation are displayed in Table 9.

Table 9.
SECANT PLANE COORDINATES - OUTPUT OF BLOCK ADJUSTMENT IN METERS

PASS POINTS	X	Y	Z
288310	-175159.941	-178654.007	-3783.068
288320	-224533.782	-118960.309	-4350.547
288330	-196938.725	-154397.051	-3873.622
289310	-140968.327	-150574.857	-2564.325
289320	-186866.970	-95485.277	-2601.182
289330	-163941.845	-124266.567	-2443.416
290310	-106548.364	-122833.069	-1039.850
290320	-152383.610	-63563.072	-1164.540
290330	-131685.875	-96569.496	-899.891
291310	-73506.450	-91626.878	-629.069
291320	-121335.359	-36081.667	-444.274
291330	-94988.940	-67988.199	-315.295
292310	-36515.376	-63241.457	449.438
292320	-79693.386	-3100.307	295.041
292330	-60177.549	-36467.791	522.021
293310	-557.116	-33201.994	880.547
293320	-46155.211	23748.689	755.439
293330	-22306.105	-11480.969	1059.436
294310	31898.162	-4934.554	690.663
294320	-3694.629	43458.533	304.189
294330	15111.681	18897.434	550.016
295310	67366.805	22135.331	82.479
295320	32090.883	64818.444	330.914
295330	49365.290	49544.761	285.874
296310	104040.087	49038.235	87.815
296320	59972.357	107751.460	-348.662
296330	78054.828	76365.232	94.902
297310	136781.254	86353.340	-1159.746
297320	100539.722	133424.766	-1563.397
297330	119761.767	104510.673	-1230.994
298310	176204.799	105752.504	-2617.263
298320	132263.976	162905.948	-3090.611
298330	154437.310	140222.139	-2944.173
299310	221333.928	118339.172	-4290.205
299320	162683.562	191183.725	-4075.060
299330	188418.605	168589.801	-4134.662

14 HELD CONTROL STATIONS

288110	-207159.931	-116964.805	-3657.839
288111	-177004.709	-175269.251	-3729.028
290110	-145821.193	-64426.763	-950.963
290111	-100286.078	-141713.588	-1517.218
292110	-93657.861	-20673.281	295.369
292111	-27028.950	-79654.702	292.163
293120	-4299.309	-52018.958	701.227
294102	-23668.327	37935.490	804.347
296110	105353.664	37357.931	-104.927
296111	67450.678	98991.786	-238.805
297120	127581.797	129937.544	-1893.776
298110	156462.108	98122.969	-1757.118
299110	165977.778	175878.308	-3777.908
299111	213537.179	124931.293	-4024.813

15 WITHHELD CONTROL STATIONS

288100	-201266.954	-146868.219	-3905.180
288101	-199181.963	-121207.223	-3451.964
288120	-200279.641	-122471.264	-3515.693
288201	-207333.116	-117576.669	-3661.657
288202	-178980.461	-176476.017	-3845.203
290201	-145925.244	-64306.415	-925.436
291120	-108298.113	-25288.198	32.891
291121	-106939.471	-26688.740	94.786
293100	-3040.499	-51135.036	747.140
293110	-28159.653	-27103.189	821.656
293121	-2734.791	-51864.218	701.808
295100	75565.486	54087.760	156.211
296201	67109.161	98615.587	-213.343
297121	127254.334	130858.812	-1904.261
299100	180311.924	125630.652	-3126.692

GEOGRAPHIC POSITIONS -- OUTPUT OF BLOCK ADJUSTMENT

PASS POINTS

	LATITUDE		LONGITUDE		Elevation (feet)
288310	34	42 26.38609	- 80	39 43.87202	1096.07686
288320	35	14 6.91221	- 81	13 2.76273	-279.18950
288330	34	55 18.68739	- 80	54 20.37638	796.27163
289310	34	57 57.28077	- 80	17 37.42388	-70.44538
289320	35	27 17.25727	- 80	48 31.79789	176.23997
289330	35	11 58.24487	- 80	33 1.74416	259.67279
290310	35	13 13.48098	- 79	55 13.16051	783.04996
290320	35	44 54.64260	- 80	26 5.64609	572.11904
290330	35	27 14.74808	- 80	12 2.23300	1293.58307
291310	35	30 16.84703	- 79	33 36.97538	-1124.96987
291320	36	0 1.95660	- 80	5 44.95660	44.75680
291330	35	42 57.32927	- 79	47 59.30026	-139.43936
292310	35	45 45.64825	- 79	9 13.58220	233.10629
292320	36	18 7.55350	- 79	38 14.22851	-13.95916
292330	36	0 10.10432	- 79	25 2.77197	370.14007
293310	36	2 2.81021	- 78	45 22.25265	557.46828
293320	36	32 46.46501	- 79	15 55.66983	555.24755
293330	36	13 46.60473	- 78	59 53.15875	1021.67941
294310	36	17 18.00507	- 78	23 41.73789	-82.35886
294320	36	43 29.95754	- 78	47 28.89599	-1127.14234
294330	36	30 12.68101	- 78	34 52.74101	-660.65358
295310	36	31 49.66979	- 77	59 51.81921	-1053.04192
295320	36	55 .94303	- 78	23 23.53281	-181.68449
295330	36	46 42.80926	- 78	11 49.19933	-418.66557
296310	36	46 10.50551	- 77	35 4.84073	1073.23836
296320	37	18 8.87137	- 78	4 24.81194	159.90532
296330	37	1 5.88875	- 77	52 22.45203	765.15397
297310	37	6 6.14785	- 77	12 40.16500	309.91260
297320	37	31 49.55763	- 77	36 44.86165	-554.28613
297330	37	16 3.46029	- 77	23 58.88423	-151.24184
298310	37	16 12.17141	- 76	45 46.80372	-338.95441
298320	37	47 32.17061	- 77	14 53.24438	-1411.50456
298330	37	35 4.08519	- 77	0 4.26612	-1072.32185
299310	37	22 26.46691	- 76	15 1.24412	-487.89597
299320	38	2 32.00796	- 76	53 47.32371	248.66309
299330	37	50 1.81199	- 76	36 33.11741	277.17958

14 HELD CONTROL STATIONS

288110	35	15 25.53695	- 81	1 37.17181	-56.53923
288111	34	44 15.06445	- 80	40 58.91790	1130.99762
290110	35	44 30.27598	- 80	21 43.80370	798.41836
290111	35	3 2.98861	- 79	50 57.40463	173.57077
292110	36	8 32.95024	- 79	47 26.25236	716.77843
292111	35	36 54.17346	- 79	2 53.97097	167.48599
293120	35	51 52.23900	- 78	47 51.36030	387.59883
294102	36	40 29.64527	- 79	0 53.15813	538.16070
296110	36	39 51.15007	- 77	34 17.49878	251.29327
296111	37	13 22.87241	- 77	59 24.02989	297.80444
297120	37	29 44.66704	- 77	18 25.65847	-290.11984
298110	37	12 17.00557	- 76	59 14.24742	393.36137
299110	37	54 13.47135	- 76	51 44.87622	51.63104
299111	37	26 6.62123	- 76	20 11.53555	-75.09492

15 WITHHELD CONTROL STATIONS

288100	34	59 19.78010	- 80	57 17.56339	550.25723
288101	35	13 13.88282	- 80	56 17.75518	46.38242
288120	35	12 32.05602	- 80	57 .06754	29.57440
288201	35	15 5.55994	- 81	1 43.45203	-13.58050
288202	34	43 34.58196	- 80	42 15.70143	1040.36233
290201	35	44 34.13316	- 80	21 47.99968	885.94229
291120	36	5 57.72387	- 79	57 9.57444	669.99247
291121	36	5 12.83931	- 79	56 14.54521	816.69433
293100	35	52 20.94618	- 78	47 1.19852	512.32645
293110	36	5 19.20237	- 79	3 45.55598	472.98178
293121	35	51 57.27979	- 78	46 49.00424	382.53015
295100	36	49 3.99475	- 77	54 11.05976	118.26105
296201	37	13 10.74701	- 77	59 38.01136	350.34280
297121	37	30 14.71046	- 77	18 38.41834	-283.95531
299100	37	26 54.19126	- 76	42 42.61679	-446.64844

Accuracy Analysis: In order to evaluate fully the accuracy potential of the analytic system, a final computer program is used to develop the inverse of the matrix of normal equations, the variances, and the standard errors in X, Y, and Z at all of the points throughout the project area.

It can be assumed that the camera parameters and the ground positions of the pass points provided by the final pass through the block adjustment solution would not change significantly should an additional pass be made. Thus the same refined image coordinates, together with the final camera parameters and ground positions for the pass points, will yield essentially the same normal equations that occurred in the final block adjustment pass. This is the basis for the accuracy-analysis program.

The standard error E of the coordinates determined at a point in the block can be expressed as $E = Qe$ where Q is the variance of the point as derived from the inverse, and e is the standard error of unit weight for the problem and is considered to be essentially equal to the photogrammetric RMS error determined in the block adjustment solution. Both Q and e are relatively independent and provide a means for the comparison of tests conducted under varying conditions.

The variance Q is affected by the geometry of the block, such as the number of photographs and the number and distribution of horizontal and vertical control. Its value can be computed from simulated photographs before the pictures are actually taken and is unaffected by poor techniques. The standard error of unit weight e is a measure of the precision of the system and is affected by the camera, comparator, effectiveness of the corrections for systematic errors, overlap, premarking, operational techniques, etc. Its value is relatively constant for a given set of techniques and allows one to upgrade the system by improving the techniques. Thus, for example, the nonmetric characteristics of the Earth Terrain Camera and the use of office-identified photo control resulted in a standard error of unit weight of nearly 13 microns for the SKYLAB study. This is significantly larger than the eight microns or less that is found in NOS operations employing metric aerial cameras and field-identified photo control.

Table 10 shows the horizontal standard errors in meters in the secant plane coordinate system for each of the 15 withheld (unweighted) photo control stations. The horizontal position RMS error computed from these values is 16.414 meters and substantiates the validity of the geodetic RMS errors found in the previous block adjustment solution.

PHOTO CONTROL STATION	X meters	Y meters
288100	9.201	9.529
288201	9.961	15.053
288202	10.164	12.360
288120	9.003	13.679
288101	8.916	14.029
290201	7.271	10.185
291120	13.554	16.164
291121	13.158	15.701
293100	15.650	11.110
293121	15.736	11.260
293110	9.967	9.494
295100	9.377	10.147
296201	7.949	7.844
297121	10.949	8.993
299100	9.084	13.678

$$\text{RMS}_X = 10.963 \quad \text{RMS}_Y = 12.216$$

$$\text{RMS}_{XY} = 16.414 \text{ meters}$$

Table 10. The standard errors in meters in the secant plane coordinate system for each of the 15 withheld (unweighted) photo control stations.

FURTHER DISCUSSION OF SKYLAB ANALYTIC AEROTRIANGULATION RESULTS

In evaluating the results of the SKYLAB aerotriangulation study, it must be remembered that these results were achieved using a strip of photography instead of a block of overlapping strips of pictures. For the case of a strip, analytic computations are usually terminated after strip adjustment because there is no evidence of a significant improvement in accuracy by continuing on through block adjustment. However, the strip adjustment of the SKYLAB photography appeared to show apparently systematic adjustment discrepancies that were assumed to be attributable to a failure to compensate completely for the systematic errors introduced by the nonmetric characteristics of the camera and/or the office-identification of photo control. For this reason, the block adjustment program was applied in an effort to optimize the accuracy of the aerotriangulation solution.

The results obtained from the block adjustment were reasonably close to the values to be expected from the SKYLAB photography. Our experience indicates that the block adjustment of a strip of metric 1:946,000 scale photography using field-identified photo control would yield a geodetic RMS error of approximately 14 meters. This figure must be modified to allow for the additional errors introduced by the nonmetric characteristics of the Earth Terrain Camera (focal plane shutter, camera lens distortion assumed to be negligible, imprecise location of the photograph principal point, etc.) and the office-identification of photo control. Assuming a maximum error of 20 meters introduced by the ETC and a maximum error of 15 meters for the office-identified photo control, the overall expected geodetic RMS error for the block adjustment of the SKYLAB strip of pictures increases to nearly 16 meters. As noted in this report, the actual geodetic RMS error was 12.218 meters for all 29 office-identified photo control stations and 15.068 meters for the 15 withheld or unweighted photo control stations.

The National Standards of Map Accuracy require 90 percent of all map points to be correct to within 1/50 inch or 0.51 mm. for maps published at scales of 1:20,000 or smaller. Statistically, the SKYLAB results indicate that 90 percent of all 29 office-identified photo control stations were held to within 20 meters, and 90 percent of the 15 withheld or unweighted stations were held to within 24.7 meters. It is evident, therefore, that if the positions of all the planimetric detail required to construct a map of the project area were developed digitally by analytic block adjustment methods, 90 percent of these planimetric points would also be correct to within less than 25 meters. Thus, the analytic aerotriangulation method

can be used in this manner with the 1:946,000 scale SKYLAB strip photography to construct a 1:50,000 scale map that will meet the National Standards of Map Accuracy.

The usual practice in mapping operations is to compile the planimetric details from stereoscopic models oriented to horizontal photo control established principally by analytic aerotriangulation procedures. Experience has shown that 90 percent of the horizontal photo control should be known to within 0.15 mm., as measured on the manuscript. This is equivalent to 24.75 meters at a map scale of 1:165,000. Thus, stereocompilation techniques can be combined with the analytic aerotriangulation methods to construct a map at 1:150,000 to 1:200,000 scale from the 1:964,000 SKYLAB strip photography.

Appendix A

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55-A

THE SKYLAB S-190B EARTH TERRAIN CAMERA

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THE SKYLAB S-190B EARTH TERRAIN CAMERA

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One of the major objectives of the Skylab manned space station to be launched in 1973 is to collect earth resources data. The Earth Resources Experiment Package (EREP) of Skylab includes instruments for collecting data in several regions of the electromagnetic spectrum, ranging from the visible to the microwave. The sensors include the S-190A multispectral camera, the S-191 infrared spectrometer, S-192 multispectral scanner, the S-193 microwave system, and the S-194 L-band radiometer. These systems have all been described elsewhere (NASA-MSD, 1971). However, a new sensor, the S-190B Earth Terrain Camera (ETC), has recently been added to EREP. Because the ETC is not as well known as the other sensors, I will describe its characteristics and indicate some potential applications of ETC photographs.

The ETC was included in the EREP of the Skylab mission as an addendum to the S-190 experiment. It is designed to supply high-resolution photographs of areas within the field of view of the other EREP sensors to aid in the interpretation of data gathered by them. In some cases information from the ETC photographs will substitute for ground truth and for photographs obtained from aircraft underflights. Furthermore, the resolution of the camera will permit certain investigations that would be impossible for any of the other EREP sensors alone.

The EROS (Earth Resources Observation Systems) Program of the Department of the Interior is interested in the ETC primarily because it has approximately the same photograph scale and ground resolution as the film-return satellite camera system which was recommended in 1967 by the National Academy of Sciences for cartographic and photogrammetric applications. That proposed satellite would be in a near-polar orbit at an altitude of 200 km and would include a metric camera of 300 mm focal length. In 1970 the Department of Interior proposed to NASA that a satellite of that type be flown, and we have a continued interest in it.

The ETC is a modified version of the Lunar Topographic Camera carried on the Apollo 13 and 14 missions. It is being built by Actron Industries, Inc. (formerly Hycon) under contract to NASA. The body is an extensively modified KA-74 reconnaissance camera body with a focal-plane shutter and vacuum film flattening. The lens has a focal length of 460 mm, a fixed aperture of f/4, color correction, and maximum radial distortion of 10 μ m. Forward image-motion compensation is provided by rocking the entire camera in its mount during the exposure.

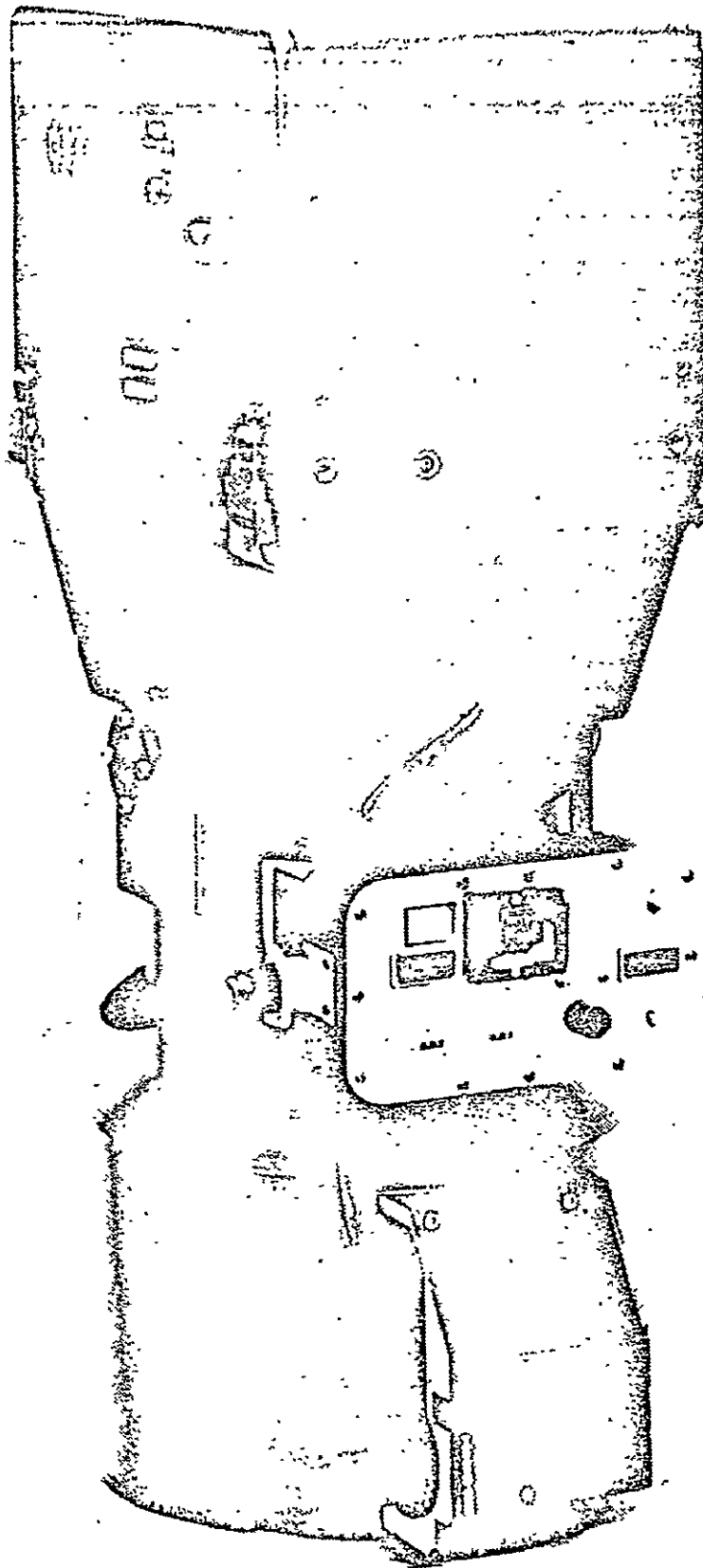


Figure 1.--The Skylab S-190B Earth Terrain Camera.

The frame format is 115 mm by 115 mm so that at the Skylab altitude the format covers an area of 109 km by 109 km. Characteristics of the camera can be summarized as follows:

Lens--460 mm focal length, f/4 fixed aperture; color corrected

Lens distortion--Radial, $\pm 10 \mu\text{m}$; tangential, $\pm 5 \mu\text{m}$

Shutter--Focal plane, bidirectional; 1/100, 1/140, 1/200 sec.

Forward-motion compensation--By rocking camera, 0 to 25 mrad/sec.

Film--125 mm (5 in.), 2-mil. base; 450 frames/roll

Format--115 x 115 mm

Framing rate--0 to 25 frames/min.

Overlap--15% Standard; 0 to 80% available

Ground coverage at nadir--109 x 109 km.

The camera has a control box with a switch for selection of manual or automatic operation. The forward-motion compensation system can be set to operate within the range of 0 to 25 mrad/sec, and the framing rate from 0 to 25 frames/min. Three shutter speeds are available, 1/100, 1/140, and 1/200 sec. Figure 1 is a photograph of the camera.

The ground resolution of the camera depends on the film used. The three films being considered are SO-242 high-resolution color, 3443 color infrared, and 3414 high-resolution black-and-white. To obtain estimated ground resolution for the different films, Actron has run computer simulations that model the forward-motion compensation system, the attitude-error rates of the spacecraft, the shutter speed, the lens characteristics, and the film and filter characteristics. Table 1 summarizes the simulations (the shutter speeds were subsequently changed). As can be seen, the expected ground resolution varies from 10 to 39 meters per optical line pair. In addition to the films listed, it is possible that a color infrared film of higher resolution will be available for at least one of the Skylab missions.

The ETC will be mounted in the Scientific Airlock of the orbital workshop of Skylab. The other EREP sensors will be located in the Multiple Docking Adapter. Figure 2 presents a view of the Skylab space station with the major components indicated. The ETC will be boresighted to record the same ground areas that the other EREP sensors are viewing.

Skylab will be operated as four missions (fig. 3). The first mission, Skylab 1, will launch the unmanned space station. The next day the first three-man crew will be launched in an Apollo spacecraft as mission Skylab 2, which will require the crew to occupy the space.

TABLE 1. Predicted ETC resolution, in meters on the ground per optical line pair.

<u>Case</u>	<u>Film</u>	<u>Shutter speed (sec)</u>	<u>High- contrast resolution (1000:1)</u>	<u>Low contrast resolution (2:1)</u>
1	3443	1/100	21	39
2	3443	1/200	21	38
3	3443	1/500	21	38
4	3414	1/100	8	15
5	3414	1/200	6	11
6	3414	1/500	5	10
7	S0-242	1/100	12	22
8	S0-242	1/200	11	20
9	S0-242	1/500	11	20

Based on computer simulations by Actron Industries, Inc., July 1971.

station for about 28 days. The crew will conduct several experiments, including the EREP series. About 2 months after the return of the Skylab 2 crew, the Skylab 3 crew will be launched to occupy the space station for as long as 56 days, again conducting a variety of experiments. The final mission, Skylab 4, will start about 1 month after the return of the Skylab 3 crew and will also have a duration of up to 56 days.

Skylab will follow a 435 km circular orbit with an inclination of 50° which will carry the station over any portion of the earth between 50°N and 50°S latitude. The normal attitude of the space station is referred to as the solar-inertial mode, required by the solar panels and the heating constraints. For the EREP experiments the space station must be maneuvered into the z-local-vertical mode. Because of thermal and other constraints, the mode can only be used for a limited number of orbits. Current plans call for approximately 60 z-local-vertical passes.

The orbital and mission constraints will thus limit the number and location of EREP data-collection passes; it will not be possible to collect data for large contiguous areas, and repetitive coverage of an area will be limited. Nevertheless, considerable data of value to various earth resources investigations should be collected during the

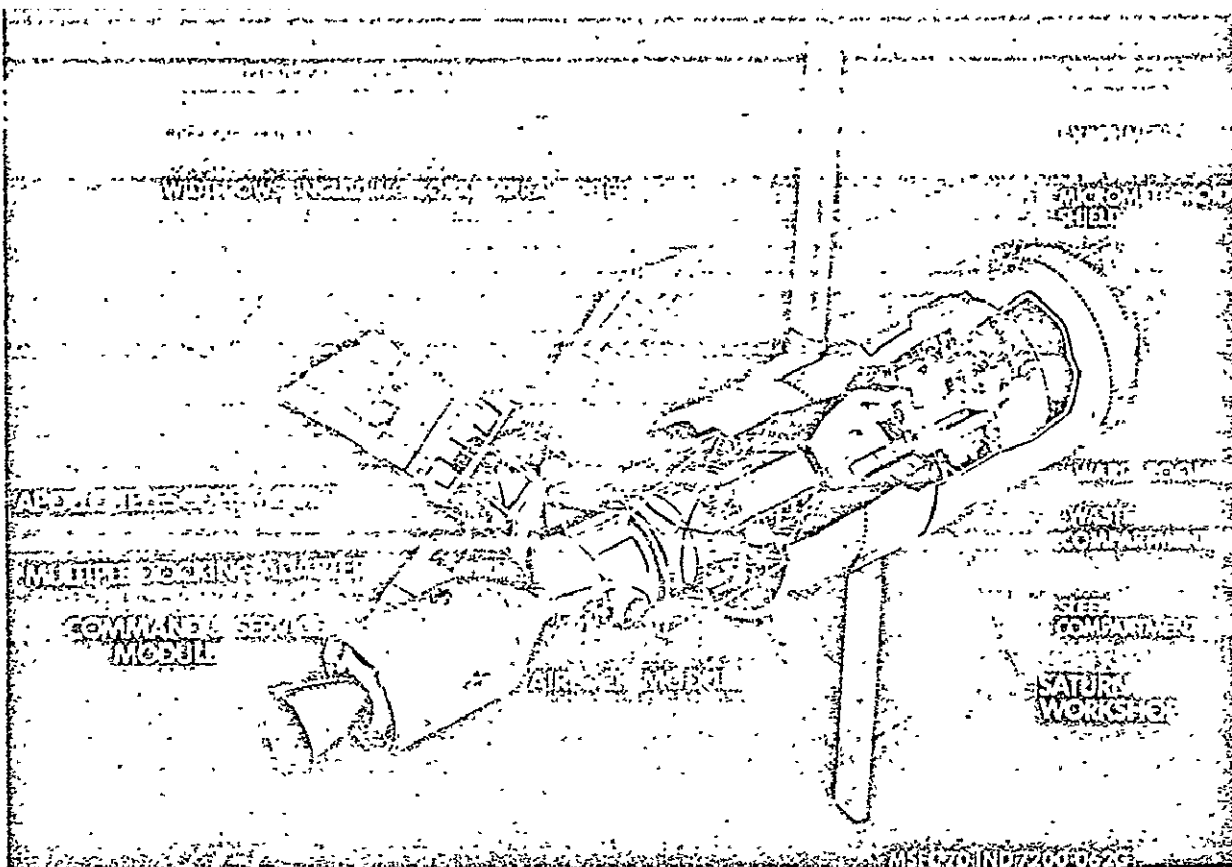


Figure 2.--The Skylab spacecraft.

Skylab program. For the Skylab 2 mission, 4 rolls of film containing 450 frames each will be available, and 6 rolls will be available for each of the other 2 missions. As many as 7200 ETC photographs may be obtained.

The exact areas of the United States where ETC photographs will be acquired have not yet been selected. Generally, the final areas for photographic coverage will be determined during the mission. Investigators whose EREP proposals were accepted by NASA have been notified of the addition of the ETC to Skylab, and many of them have requested ETC photographs of their test areas. In addition, many Federal and State agencies have requested ETC photographs of specific areas. The requests are being coordinated with the Skylab mission planners in an effort to take photographs of as many areas of interest as orbits, weather, and other constraints will permit. ETC photographs will be available to the public at nominal cost through the EROS Data Center of the U.S. Geological Survey, at Sioux Falls, S. Dak.

The design of the ETC will limit its applications. First, the ETC is not a metric camera in the photogrammetric sense. Because the image frame is a part of the removable film magazine and because of the use of a focal-plane shutter, the geometric quality of the photographs is limited. The principal point cannot be precisely located, and

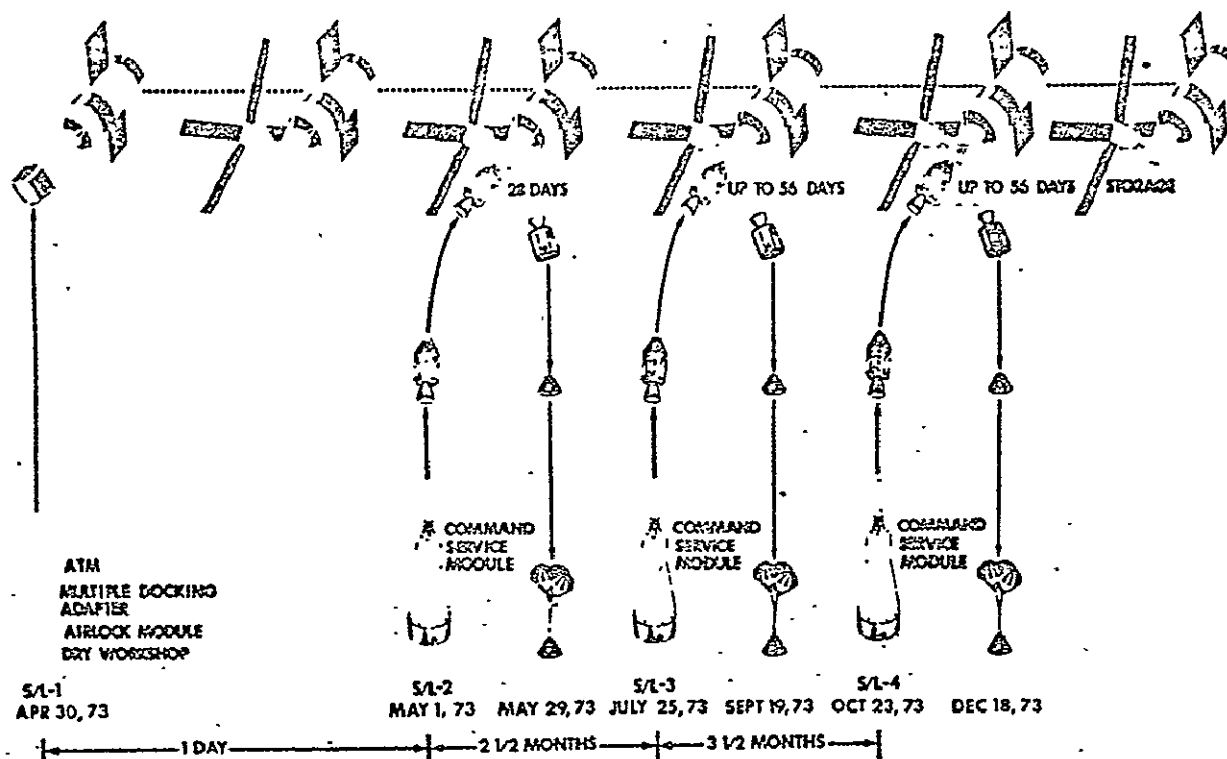


Figure 3.--Sequence of Skylab missions.

therefore analytical applications will be limited. The ETC has a limited field of view, 14° . When the camera is operated for 60% overlap, the base-height ratio is only 0.15; thus, the use of the ETC for stereoscopic height determination will be especially limited.

In spite of the limitations, the ETC represents a significant advance in camera systems for earth resources observations from space. The ground resolution is considerably better than that of any camera previously used. A recent paper by Colvocoresses (1972) compares the image resolution of ERTS, Skylab, and Gemini/Apollo space photographs. Table 2, compiled from data in that paper, summarizes the ground resolution of the various systems. From the tabulated data, it is obvious that the ETC has ground resolution from 3 to 20 times better than the other space photographic systems. Moreover, the ETC fills the gap between the other space systems and high-altitude aircraft cameras, which normally have ground resolution of 1 m or better.

The ETC will also permit a comparison of multispectral and multi-spatial data collection. The S-190A multispectral camera will provide narrow-spectral-band photographs useful for multispectral interpretation. The ETC, on the other hand, will provide photographs of a different

TABLE 2. Comparison of Ground Resolution for Space Imaging Systems. Ground resolution given in terms of the photographic criterion of optical line pairs, in meters on the ground per line pair.

<u>System</u>	<u>High-contrast (100:1 or 1000:1)</u>	<u>Low-contrast (2:1 or 1.6:1)</u>
ERTS-A		
RBV, green band	126	180
RBV, red band	126	180
RBV, infrared band	156	275
MSS	244	316
Skylab		
S-190A		
High-resolution film	22	38
Low-resolution film	49	99
S-190B (ETC)		
High-resolution film	10	15
Low-resolution film	20	38
Gemini/Apollo		
High-resolution film	50	70
Low-resolution film	80	125

scale and resolution, which can be compared with the S-190A photographs and thus provide an evaluation of multispatial data.

The S-190A and ETC photographs may also be used with aircraft photographs for multistage sampling, a technique that starts with the interpretation and classification of small-scale photographs of a large region. Interpretations are made on progressively larger scale photographs of smaller and smaller areas within the large region. The application of the technique in forestry has been described by Langley (1969).

Therefore, the principal applications of ETC photographs will be in experiments where high resolution is required. Each individual photograph will be a nearly orthographic view of the ground, with

rather low distortion within the frame. The high resolution will greatly benefit experiments in which photointerpretation is important.

An example of the kind of experiment planned for the ETC photographs is photomapping at 1:250,000 and 1:100,000 scale. The image scale of the ETC photographs will be about 1:945,000. Doyle (1971) has proposed criteria for the resolution required for photomapping and the useful enlargement of the photographs:

$$R_g = 10^{-4} S_m$$

where

R_g = required ground resolution (m/lp)

S_m = map scale number.

The suggested criterion for photographic enlargement is expressed as

$$M_a = \frac{r_p}{10}$$

where

r_p = original photo resolution (lp/mm)

M_a = allowable enlargement from photograph scale.

According to criteria, the required ground resolution for 1:250,000 and 1:100,000 scale photomaps is 25 m and 10 m. Assuming the use of 3414 film, the approximate photograph resolution is 80 lp/mm and the allowable enlargement is 8X. Enlargement to 1:250,000 scale would require 3.8X and to 1:100,000 would require 9.5X. At 1:100,000 scale the image would still have a theoretical resolution of 8 lp/mm, which may be satisfactory in the practical sense.

The U.S. National Map Accuracy Standards (NMAS) require that 90% of the well defined points tested be no more than 0.5 mm from their correct position at map scale. For a 1:250,000-scale map the tolerance converts to 125 m while for a 1:100,000-scale map it is 50 m. A computer program prepared by DBA Systems, Inc., for the Geological Survey has been used to determine how much relief can be tolerated before planimetric image displacement exceeds NMAS. The program includes the effects of earth curvature, atmospheric refraction, terrain relief, location of the image in the photograph format, and map-projection scale factor. The computer analysis indicates that about 500 m of relief can be tolerated at the extremes of the usable photo format for the photograph to meet the standards for 1:250,000-scale mapping. For mapping at 1:100,000 scale, only about 300 m of relief can be tolerated. The UTM was used as the map projection in the analysis.

Conditions which could significantly affect the positional accuracy of the images, however, are the effects of the focal-plane shutter and of errors in the forward motion compensation (FMC) system.

A NASA study (McDermitt, 1971) considered the effects of spacecraft residual rates, FMC errors, earth rotation, shutter type, and spacecraft rigidity. The study concluded that, in the worst case, errors due to the sources considered would amount to about 35 μ m displacement between the leading and trailing edge of an image. That is, the dimension of a discrete image will be changed 35 μ m in the direction of motion. Much of the error could be reduced by proper operation of the camera, but a random component of about 22 μ m would probably remain, equivalent to 21 m on the ground. Thus, there is some question whether the 1:100,000 positional accuracy requirement can be met. Maps at the scale of 1:250,000, however, appear to be well within the capability of the camera. The USGS plans to conduct photomapping experiments at both scales in order to determine the usefulness of space photographs of ETC resolution.

- Other mapping experiments planned for the ETC photographs include map revision and thematic mapping. Experiments will be conducted to determine the types of map revision information that can be derived from the photographs and applied to maps at scales of 1:24,000 and smaller.

Thematic mapping consists of the preparation of maps depicting such data as vegetation distribution, surface-water distribution, snow cover, and the massed works of man. Thematic mapping experiments at scales of 1:250,000 and 1:100,000 are planned, using color infrared photographs as the most suitable input for this kind of mapping.

ETC photographs will also be used for land-use mapping; urban development studies; sediment loads and dynamics of San Francisco Bay; geological synthesis of the Colorado Plateau; study of hazards and tectonics in the Cascades volcanoes; marine geology of the Pacific Northwest; and geologic studies of areas in California, Oregon, Oklahoma, and a portion of the Great Plains. The experiments will depend largely on photointerpretation of the ETC photographs. Some will require normal color photographs while others will require color infrared photographs. One of the primary objectives of the experiments will be comparison of ETC photographs with aircraft photos, S-190A photos, and ERTS-A images. Thus, a better assessment can be made of the scale and the resolution that are optimum for each particular investigation. The results of the experiments will be of great value in defining future data-collection systems for earth resources.

In conclusion, the Earth Terrain Camera provides an opportunity to acquire high-resolution space photographs for the study of mapping and for investigations of earth resources. The camera fills the gap between high-altitude aircraft photographs and other hitherto random space photographs. Although the camera has several limitations from the photogrammetric standpoint, it will supply high-resolution photographs of value to several disciplines.

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Appendix B

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Line	Code	Statement	Address	Count
4	READ	558,A(1,K),A(2,K),A(3,K),ITEST	8600	58
		IS=A(1,K)	8600	58
		IF(JERRY.NE.0) GO TO 321	8600	59
		NEIL=HTCON	8600	60
60		JOYCE=A(2,K)	8600	61
		MORT=A(3,K)	8600	62
		GO TO 322	8600	63
321		NEIL=A(2,K)	8600	64
		IF(NEIL.EQ.0) NEIL=A(3,K)	8600	65
65		IF(A(2,K).NE.0.0) JOYCE=HTCON	8600	66
		IF(A(3,K).NE.0.0) MORT=HTCON	8600	67
322		PRINT 574,IS,NEIL,JOYCE,MORT	8600	68
		JOYCE=MORT=0	8600	69
		IF(ITEST) 5,5,6	8600	70
70	5	K=K+1	8600	71
		IF(K-250) 4,4,27	8600	72
27		PRINT 570	8600	73
		STOP	8600	74
6		J=1	8600	75
75		DO 7 I=2,K	8600	76
		IF(A(I,I).GE.A(I,I-1)) GO TO 7	8600	77
		J=-1	8600	78
		DO 8 L=1,3	8600	79
		SAVE=A(L,I)	8600	80
80		A(L,I)=A(L,I-1)	8600	81
		A(L,I-1)=SAVE	8600	82
8		CONTINUE	8600	83
7		CONTINUE	8600	84
		IF(J.LT.0) GO TO 6	8600	85
85	C	READ IN ALL GROUND COORDINATES FOR BLOCK	8600	86
		LEN=0 \$ NEXT=IFIRST=1	8600	87
		IQ=24012005340000000000	8600	88
		CALL DBUF(0)	8600	89
		CALL DBUF(1)	8600	90
90		J=1	8600	91
	9	NCON = J+5	8600	92
		NCON = NCON-2	8600	93
		CALL DBUF(1)	8600	94
		DECODE(80,527,BUFF(IXBUF)) (G(I),I=J,NCON),ITEST	8600	95
95		DO 10 L=1,K	8600	96
		IF(G(J)-A(1,L)) 11,12,10	8600	97
10		CONTINUE	8600	98
		GO TO 11	8600	99
12		G(J+4)=A(2,L)	8600	100
100		G(J+3)=A(3,L)	8600	101
		GO TO 13	8600	102
	11	G(J+4)=G(J+5)=0.	8600	103
	13	IF(ITEST) 14,14,15	8600	104
	14	J=J+6	8600	105
105		GO TO 9	8600	106
	15	NCON=NCON/6	8600	107
		DO 22 J=1,256,3	8600	108
		DO 22 I=1,207	8600	109
		A(I,J)=0.	8600	110
110	22	CONTINUE	8600	110

PROGRAM		CDC 6630 FTN V3.0-324 OPT=2		04/02/75	20.40.54.	PAGE	4
		DECODE(80,526,BUFF(IXBUF))(B(J,IMAGE),J=1,3),ITEST	B600	170			
		IF(ITEST)18,18,21	B600	1			
	18	IMAGE=IMAGE+1	B600	2			
		IF(IMAGE-30)36,36,20	B600	3			
170	20	IS=0(1,90)	B600	4			
		PRINT 545,IS	B600	5			
		STOP	B600	6			
	C	SET UP ORDER LIST - STORE IMAGES BY OBJECT - SET UP OBJECT FILE	B600	178			
	C	LIST FOR PHOTO - SAVE COORDINATES OF POTENTIAL RESECTION OBJECTS	B600	179			
175	21	LAST=0	B600	180			
		IF(B(2,50))39,39,38	B600	181			
	38	NROW=4	B600	182			
		GO TO 42	B600	183			
	39	IF(B(3,50))40,40,41	B600	184			
180	41	NROW=1	B600	185			
		NMI=6	B600	186			
		LAST=1	B600	187			
		GO TO 43	B600	188			
	40	NROW=1	B600	189			
185	42	NMI=IMAGE	B600	190			
	43	DO 23 K=NROW,NMI	B600	191			
		J=B(1,K)*.000001	B600	192			
		FK=J*1000000	B600	193			
		FK=B(1,K)-FK	B600	194			
190		NU=1	B600	195			
	32	MORT=NU-86*((NU-1)/86)	B600	196			
		M=(1+(NU-1)/86)*9-8	B600	197			
		IF(A(M,3*MORT-2))25,24,25	B600	198			
195	24	A(M,3*MORT-2)=B(1,K)	B600	199			
		A(M,3*MORT-1)=B(2,K)	B600	200			
		A(M,3*MORT)=B(3,K)	B600	201			
		LINE=LINE+1	B600	202			
		I=6*NU-5	B600	203			
		IF(G(1)-FK)26,49,26	B600	204			
200	26	G(12001)=G(I)	B600	205			
		G(12002)=G(I+1)	B600	206			
		G(12003)=G(I+2)	B600	207			
		G(12004)=G(I+3)	B600	208			
		G(12005)=G(I+4)	B600	209			
205		G(12006)=G(I+5)	B600	210			
		NU=NU+1	B600	211			
		DO 28 L=NU,NCON	B600	212			
		IF(G(6*L-5)-FK)28,29,28	B600	213			
210	28	CONTINUE	B600	214			
		IS=FK	B600	215			
		PRINT 528,IS	B600	216			
		STOP	B600	217			
	29	G(I)=G(6*L-5)	B600	218			
		G(I+1)=G(6*L-4)	B600	219			
215		G(I+2)=G(6*L-3)	B600	220			
		G(I+3)=G(6*L-2)	B600	221			
		G(I+4)=G(6*L-1)	B600	222			
		G(I+5)=G(6*L)	B600	223			
		G(6*L-5)=G(12001)	B600	224			
220		G(6*L-4)=G(12002)	B600	225			

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PROGRAM B600

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		G(6*L-3)=G(12003)	0600	226
		G(6*L-2)=G(12004)	0600	227
		G(6*L-1)=G(12005)	0600	228
		G(6*L)=G(12006)	0600	229
225	49	NEIL=NEIL+1	0600	230
		A(JOYCE,NEIL)=G(I)	0600	231
		IF(K-9)50,50,23	0600	232
	50	B(1,K+60)=G(I+1)	0600	233
		B(2,K+60)=G(I+2)	0600	234
230		B(3,K+60)=G(I+3)	0600	235
		GO TO 23	0600	236
	25	IF(FK-G(6*NU-5))30,31,30	0600	237
	30	NU=NU+1	0600	238
		GO TO 32	0600	239
235	31	L=M+1	0600	240
	35	IF(A(L,3*MORT-2))33,34,33	0600	241
	33	L=L+1	0600	242
		IF(L-M-8)35,35,37	0600	243
	37	IS=G(6*NU-5)	0600	244
240		PRINT 537,IS	0600	245
		STOP	0600	246
	34	A(L,3*MORT-2)=B(1,K)	0600	247
		A(L,3*MORT-1)=B(2,K)	0600	248
		A(L,3*MORT)=B(3,K)	0600	249
245		I=6*NU-5	0600	250
		GO TO 49	0600	251
	23	CONTINUE	0600	252
		IF(LAST)46,46,44	0600	253
	44	IF(IMAGE-9)46,46,45	0600	254
250	45	NROW=10	0600	255
		LAST=0	0600	256
		GO TO 42	0600	257
	46	A(JOYCE,31)=NEIL	0600	258
255	C		0600	259
	C	PHOTO RESECTION PHASE	0600	260
	C		0600	261
	C	INITIAL APPROXIMATIONS OF CAMERA PARAMETERS	0600	262
	310	N=0	0600	267
		DO 51 J=1,2	0600	268
260		C(J,1)=B(J,66)	0600	269
		C(J,2)=0.	0600	270
		C(J,3)=1.	0600	271
	51	CONTINUE	0600	272
265	C	ADJUST APPROXIMATE AZIMUTH PARAMETERS FOR SWING AND Z0	0600	273
		D(1,1)=B(2,4)-B(2,5)	0600	274
		D(1,2)=B(3,4)-B(3,5)	0600	275
		D(2,1)=B(1,64)-B(1,65)	0600	276
		D(2,2)=B(2,64)-B(2,65)	0600	277
		D(2,4)=D(2,1)*D(2,1)+D(2,2)*D(2,2)	0600	278
270		D(1,3)=(D(2,1)*D(1,1)+D(2,2)*D(1,2))/D(2,4)	0600	279
		D(2,3)=(D(2,2)*D(1,1)-D(2,1)*D(1,2))/D(2,4)	0600	280
		SCALE=SQRT(D(1,3)*D(1,3)+D(2,3)*D(2,3))	0600	281
		C(3,2)=D(2,3)/SCALE	0600	282
		C(3,1)=FL/SCALE	0600	283
275		C(3,3)=D(1,3)/SCALE	0600	284

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C      ORIENTATION FACTORS IN 2 ARRAY
52 N=N+1
IF(N-5) 54,54,53
53 IS=0(1,50)
PRINT 535,IS
PRINT 557,(IS,(C(J,I),J=1,3),I=1,2)
IRE=2
GO TO 70
54 K=0
285 92 C(1,K+4)=C(2,K+3)*C(3,K+3)
C(1,K+5)=-C(2,K+3)*C(3,K+2)
C(1,K+6)=C(2,K+2)
C(1,K+10)=-C(2,K+2)*C(3,K+3)
C(1,K+11)=C(2,K+2)*C(3,K+2)
C(1,K+12)=C(2,K+3)
C(2,K+10)=C(1,K+4)*C(1,K+2)
C(2,K+11)=C(1,K+5)*C(1,K+2)
C(2,K+12)=C(1,K+2)*C(2,K+2)
C(3,K+10)=-C(1,K+4)*C(1,K+3)
C(3,K+11)=-C(1,K+5)*C(1,K+3)
C(3,K+12)=-C(1,K+3)*C(2,K+2)
C(2,K+4)=C(1,K+3)*C(3,K+2) + C(2,K+12)*C(3,K+3)
C(2,K+5)=C(1,K+3)*C(3,K+3) - C(2,K+12)*C(3,K+2)
C(2,K+6)=-C(1,K+2)*C(2,K+3)
300 C(3,K+4)=C(1,K+2)*C(3,K+2) + C(1,K+10)*C(1,K+3)
C(3,K+5)=C(1,K+2)*C(3,K+3) + C(1,K+11)*C(1,K+3)
C(3,K+6)=C(1,K+3)*C(2,K+3)
DO 55 I=7,9
M=K+I
305 C(1,M)=0.
C(2,M)=-C(3,M-3)
C(3,M)=C(2,M-3)
C(I-6,K+13)=C(I-6,K+5)
C(I-6,K+14)=-C(I-6,K+4)
310 C(I-6,K+15)=0.
55 CONTINUE
GO TO(56,71),IGO
C      CLEAR NORMAL EQUATION D ARRAY TO ZERO
315 56 DO 57 I=1,6
DO 57 J=I,7
D(I,J) = 0.
57 CONTINUE
C      COMPUTE P TERMS FOR PASS POINTS USED FOR RESECTION
320 IF(B(2,50))59,59,58
58 M=4
NROW=8
GO TO 62
59 IF(B(3,50))61,61,60
325 60 M=1
NROW=5
GO TO 62
61 M=1
NROW=9
330 62 DO 63 NU=M,NROW
DO 64 K=1,3

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PROGRAM		B600	CDC 6610 FPN V3.0-324 OPT=2		04/02/75	20.40.54.	PAGE	7
		C(K,16)=B(K,NU+60)-C(K,1)	B600		340			
	64	CONTINUE	B600		341			
		K=4	B600		342			
		DO 65 L=1,20	B600		343			
335		DO 65 I=1,3	B600		344			
		C(I,L)=C(I,K)*C(I,16) + C(2,K)*C(2,16) + C(3,K)*C(3,16)	B600		345			
		K=K+1	B600		346			
	65	CONTINUE	B600		347			
		DO 66 I=1,2	B600		348			
340		DO 67 L=1,4	B600		349			
		P(I,L)=(B(I+1,NU)*C(3,L+15) + FL *C(I,L+15))/C(3,17)	B600		350			
	67	CONTINUE	B600		351			
		DO 68 L=5,7	B600		352			
		P(I,L)=(-B(I+1,NU)*C(L-4,5) - FL *C(L-4,I+3))*C(3,17)/C(3,17)	B600		353			
345	68	CONTINUE	B600		354			
		P(I,8)=-P(I,1)	B600		355			
	66	CONTINUE	B600		356			
	C	CONTRIBUTION TO NORMAL EQUATIONS	B600		357			
		DO 63 I=1,6	B600		358			
350		DO 63 J=1,7	B600		359			
		DO 63 K=1,2	B600		360			
		D(I,J)=D(I,J)+P(K,I+1)*P(K,J+1)	B600		361			
	63	CONTINUE	B600		362			
	C	FORWARD SOLUTION	B600		363			
355		DO 69 I=1,6	B600		364			
		SQR = 1./SQRT(D(I,1))	B600		365			
		DO 72 J=1,7	B600		366			
		D(I,J)=D(I,J)*SQR	B600		367			
	72	CONTINUE	B600		368			
360		IF(I-6)73,74,74	B600		369			
	73	IP1=I+1	B600		370			
		DO 69 L=IP1,6	B600		371			
		DO 69 J=L,7	B600		372			
		D(L,J)=D(L,J)-D(I,L)*D(I,J)	B600		373			
365	69	CONTINUE	B600		374			
	C	BACK SOLUTION	B600		375			
	74	D(6,7)=D(6,7)/D(6,6)	B600		376			
		DO 75 I=1,5	B600		377			
		NMI=6-I	B600		378			
370		NMIP1=NMI+1	B600		379			
		DO 76 J=NMIP1,6	B600		380			
		D(NMI,7)=D(NMI,7)-D(J,7)*D(NMI,J)	B600		381			
	76	CONTINUE	B600		382			
		D(NMI,7)=D(NMI,7)/D(NMI,NMI)	B600		383			
375	75	CONTINUE	B600		384			
		DO 77 I=4,6	B600		385			
		D(I,7)=D(I,7)*C(3,1)	B600		386			
	77	CONTINUE	B600		387			
	C	ADD LEAST SQUARES RESULTS TO CAMERA PARAMETERS IN C ARRAY	B600		388			
380		DO 78 J=1,3	B600		389			
		C(J,1)=C(J,1)+D(J,3,7)	B600		390			
		C(J,4)=D(J,7)	B600		391			
		C(J,5)=SQRT(1.-C(J,4)*C(J,4))	B600		392			
		C(J,6)=C(J,2)*C(J,5)+C(J,3)*C(J,4)	B600		393			
385		C(J,7)=C(J,3)*C(J,5)-C(J,2)*C(J,4)	B600		394			

B
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000 0000 1 111 1000-007 01 1-2 070000 1 0000000

Line	Label	Code	Statement	Address	Count
			C(J,2)=C(J,6)	8600	395
			C(J,3)=C(J,7)	8600	396
			CONTINUE	8600	397
390	C	78	TEST MAGNITUDE OF CORRECTIONS FOR ORIENTATION PARAMETERS	8600	398
			DO 79 I=1,3	8600	399
			IF(ABS(D(I,7))-0.00001)79,79,52	8600	400
			CONTINUE	8600	401
	C	79	STORE CAMERA PARAMETERS AS COMPUTED FROM PHOTO RESECTION	8600	402
395		70	CAM(IPHO,1)=B(1,50)	8600	403
			DO 80 J=1,3	8600	404
			CAM(IPHO,J+8)=C(J,3)	8600	405
			CAM(IPHO,J+5)=C(J,2)	8600	406
			CAM(IPHO,J+2)=C(J,1)	8600	407
		80	CONTINUE	8600	408
400			IF(B(1,51))16,16,81	8600	409
		81	NROW=IPHO	8600	410
			MC=MC+1	8600	411
			IGO = 2	8600	412
			LOS=2*LOS+3	8600	413
405			IF(IRE-2)48,82,82	8600	414
		82	STOP	8600	415
	C		BLOCK SIZE	8600	416
		95	IF(LINE-1978)84,84,85	8600	417
		85	PRINT 544,LINE	8600	418
410			STOP	8600	419
		84	PRINT 543,IPHO,LINE	8600	420
	C			8600	421
	C		BLOCK ADJUSTMENT PHASE	8600	422
415	C			8600	423
		271	DO 86 I=1,258	8600	424
			DO 86 J=I,259	8600	425
			A(I,J)=C	8600	426
		86	CONTINUE	8600	427
	C		RESET PLATE WITH NEW OBJECTS AND FORM C ARRAY ROWS 1-15 FOR ALL	8600	432
420	C		PLATES ON WHICH THE NEW OBJECTS APPEAR	8600	433
		301	INSECT=0	8600	434
		234	KDISK=1	8600	435
			ME=1	8600	436
		105	NA=CAM(ME,12)	8600	437
425			IF(NA.EQ.0) GO TO 297	8600	438
			CALL READMS(11,B,NA,KDISK)	8600S	7
			KDISK=KDISK+(NA+407)/408	8600	440
		297	IF(ME-1)87,87,96	8600	441
		87	IF(IPHO-43)88,88,89	8600	442
430		88	LAST=IPHO	8600	443
			GO TO 94	8600	444
		89	LAST=43	8600	445
			GO TO 94	8600	446
		96	NMI=LAST=ME+42	8600	447
435			IF(NMI-IPHO)104,104,123	8600	448
		94	NMI=1	8600	449
		104	DO 71 L=NMI, LAST	8600	450
			K=20*(L-1) - 860*((L-1)/43)	8600	451
			DO 97 J=1,3	8600	452
440			C(J,K+1)=CAM(L,J+2)	8600	453

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PROGRAM .. B600		CDC 6610 FTN V3.0-324 OPT=2 04/02/75 20.40.54.		PAGE	9
		C(J,K+2)=CAM(L,J+5)	B600	454	
		C(J,K+3)=CAM(L,J+8)	B600	455	
97		CONTINUE	B600	456	
		IF(INSECT.EQ.0) GO TO 92	B600	457	
445		C(1,K+4)=C(2,K+3)*C(3,K+3)	B600	458	
		C(1,K+5)=-C(2,K+3)*C(3,K+2)	B600	459	
		C(1,K+6)=C(2,K+2)	B600	460	
		C(2,K+4)=C(1,K+3)*C(3,K+2) + C(1,K+2)*C(2,K+2)*C(3,K+3)	B600	461	
		C(2,K+5)=C(1,K+3)*C(3,K+3) - C(1,K+2)*C(2,K+2)*C(3,K+2)	B600	462	
450		C(2,K+6)=-C(1,K+2)*C(2,K+3)	B600	463	
		C(3,K+4)=C(1,K+2)*C(3,K+2) - C(2,K+2)*C(3,K+3)*C(1,K+3)	B600	464	
		C(3,K+5)=C(1,K+2)*C(3,K+3) + C(2,K+2)*C(3,K+2)*C(1,K+3)	B600	465	
		C(3,K+6)=C(1,K+3)*C(2,K+3)	B600	466	
		CONTINUE	B600	467	
455	C	NEW OBJECTS BEING PROCESSED ON PLATE	B600	468	
123		CONTINUE	B600	469	
303		N=1	B600	470	
		IF(INSECT.EQ.0.AND.NA.EQ.) GO TO 169	B600	471	
		IF(INSECT.EQ.1) GO TO 360	B600	472	
460	110	J=B(1,N)*.000001	B600	473	
		FK=J	B600	474	
		DO 111 L=1,IPHO	B600	475	
		IF(FK-CAM(L,1))111,115,111	B600	476	
	111	CONTINUE	B600	477	
465	115	K=20*(L-1) - .860*((L-1)/43)	B600	478	
		IF(LARRY)109,109,107	B600	479	
	107	FL=CAM(L,2)	B600	480	
	109	FK=J*1000000	B600	481	
		FK=B(1,N)-FK	B600	482	
470		IF(N-1)125,125,126	B600	483	
	125	SQR=FK	B600	484	
		DO 146 I=1,3	B600	485	
		E(I,50)=0.	B600	486	
		DO 146 J=I,3	B600	487	
475		E(I,J)=0.	B600	488	
	146	CONTINUE	B600	489	
		MORT=0	B600	490	
		DO 114 NU=1,LINE	B600	491	
		IF(SQR-G(6*NU-5))114,126,114	B600	492	
480	114	CONTINUE	B600	493	
	126	IF(FK-SQR)113,112,113	B600	494	
	C	COMPUTE C ARRAY COLS 16 THROUGH 20 FOR IMAGE	B600	495	
	112	MORT=MORT+1	B600	496	
		D(1,MORT)=NCON=L	B600	497	
485		DO 116 I=1,3	B600	498	
		M=6*NU-5+I	B600	499	
		C(I,K+16)=G(M)-C(I,K+1)	B600	500	
	116	CONTINUE	B600	501	
		J=K+4	B600	502	
490		DO 117 L=17,20	B600	503	
		M=K+L	B600	504	
		DO 117 I=1,3	B600	505	
		C(I,M)=C(1,J)*C(1,K+16) + C(2,J)*C(2,K+16) + C(3,J)*C(3,K+16)	B600	506	
		J=J+1	B600	507	
495	117	CONTINUE	B600	508	

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PROGRAM		B600	CDC 6610 FTN V3.0-324	OPT=2	04/02/75	20.40.54.	PAGE	10
	C	COMPUTE P COEFFICIENTS OF OBSERVATION EQUATIONS FOR IMAGE	B600		512			
		DO 118 I=1,2	B600		513			
		DO 119 L=1,4	B600		514			
		M=K+L	B600		515			
500		P(I,L)=(B(I+1,N)*C(3,M+15)+FL*C(I,M+16))/C(3,K+17)	B600		516			
	119	CONTINUE	B600		517			
		M=K+I	B600		518			
		DO 118 L=5,7	B600		519			
		P(I,L)=(-B(I+1,N)*C(L-4,K+5)-FL*C(L-4,M+3))*CAM(1,5)/C(3,K+17)	B600		520			
505	118	CONTINUE	B600		521			
	C	ARRANGE AUGMENTED COEFFICIENT MATRIX	B600		522			
		DO 120 I=3,4	B600		523			
		DO 121 L=1,3	B600		524			
		P(I,L)=-P(I-2,L+4)	B600		525			
510	121	CONTINUE	B600		526			
		DO 122 L=4,9	B600		527			
		P(I,L)=P(I-2,L-2)	B600		528			
	122	CONTINUE	B600		529			
		P(I,10)=-P(I-2,1)	B600		530			
515	120	CONTINUE	B600		531			
	C	WEIGHTING CONTROL STATION OBSERV. EQUATIONS FOR TARGET QUALITY	B600		7			
		M=6*NU-1	B600		533			
		IF(G(M))130,129,130	B600		534			
	129	IF(G(M+1))135,136,135	B600		535			
520	135	IF(JERRY)131,131,137	B600		536			
	137	WEIGHT=G(M+1)	B600		537			
		GO TO 133	B600		538			
	130	IF(JERRY)131,131,132	B600		539			
	131	WEIGHT=WTCON	B600		540			
525		GO TO 133	B600		541			
	132	WEIGHT=G(M)	B600		542			
	133	DO 134 I=3,4	B600		543			
		DO 134 J=1,10	B600		544			
		P(I,J)=P(I,J)*WEIGHT	B600		545			
530	134	CONTINUE	B600		546			
	C	WEIGHTING EQUATIONS FOR LOCATION OF IMAGE ON PLATE (RESOLUTION)	B600		547			
	136	RADIUS=SQRT(B(2,N)**2 + 3(3,N)**2)	B600		548			
		IF(RADIUS-.07)143,143,138	B600		549			
	138	IF(RADIUS-.12)139,139,140	B600		550			
535	139	WEIGHT=WT712	B600		551			
		GO TO 141	B600		552			
	140	WEIGHT=WT12P	B600		553			
	141	DO 142 I=3,4	B600		554			
		DO 142 J=1,10	B600		555			
540		P(I,J)=P(I,J)*WEIGHT	B600		556			
	142	CONTINUE	B600		557			
	C	COMPUTE NORMAL EQUATIONS FOR IMAGE AND STORE IN E AND A ARRAYS	B600		558			
	143	DO 144 I=5,13	B600		559			
		DO 144 J=1,10	B600		560			
545		P(I,J)=0.	B600		561			
	144	CONTINUE	B600		562			
		DO 145 I=1,9	B600		563			
		DO 145 IP1=3,4	B600		564			
		DO 145 M=I,10	B600		565			
550		P(I+4,M)=P(I+4,M)+P(IP1,I)*P(IP1,M)	B600		566			

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PROGRAM		B600	CDC 6630 FTN V3.0-324 OPT=2 04/02/75 20.40.54.		PAGE	11
	145	CONTINUE	8600	567		
		DO 147 I=1,3	8600	568		
		DO 147 J=I,3	8600	569		
		E(I,J)=E(I,J)+P(I+4,J)	8600	570		
555	147	CONTINUE	8600	571		
		E(1,58)=E(1,58)+P(5,10)	8600	572		
		E(2,58)=E(2,58)+P(6,10)	8600	573		
		E(3,58)=E(3,58)+P(7,10)	8600	574		
		DO 148 I=1,3	8600	575		
560		NEIL=6*MORT-3	8600	576		
		DO 148 J=4,9	8600	577		
		NEIL=NEIL+1	8600	578		
		E(I,NEIL)=P(I+4,J)	8600	579		
	148	CONTINUE	8600	580		
565		IF(IPHO-43)200,200,201	8600	581		
	201	IF(ME+42-IPHO)202,203,203	8600	582		
	202	I=6*NCON-6-6*(ME-1)	8600	583		
		GO TO 204	8600	584		
	203	I=6*NCON-6-6*(IPHO-43)	8600	585		
570		GO TO 204	8600	586		
	200	I=6*NCON-6	8600	587		
	204	DO 149 K=8,13	8600	588		
		M=K-4	8600	589		
		J=I	8600	590		
575		I=I+1	8600	591		
		A(I,LLL)=A(I,LLL)+P(K,10)	8600	592		
		DO 149 L=M,9	8600	593		
		J=J+1	8600	594		
		A(I,J)=A(I,J)+P(K,L)	8600	595		
580	149	CONTINUE	8600	596		
		N=N+1	8600	597		
		IF(N-NA/3)110,110,151	8600	598		
	151	KC=1	8600	599		
	C	APPLY POSITION WEIGHTS OF CONTROL STATIONS	8600	600		
585	113	IF(G(6*NU-1))152,152,153	8600	601		
	153	IF(JERRY)154,154,155	8600	602		
	154	E(1,1)=E(1,1)*G(6*NU-1)	8600	603		
		E(2,2)=E(2,2)*G(6*NU-1)	8600	604		
		GO TO 152	8600	605		
590	155	E(1,1)=E(1,1)*WTCON	8600	606		
		E(2,2)=E(2,2)*WTCON	8600	607		
	152	IF(G(6*NU))156,156,157	8600	608		
	157	IF(JERRY)159,159,158	8600	609		
	159	E(3,3)=E(3,3)*G(6*NU)	8600	610		
595		GO TO 156	8600	611		
	158	E(3,3)=E(3,3)*WTCON	8600	612		
	C	FORWARD SOLUTION OF NORMAL EQUATIONS FOR NEW OBJECT	8600	613		
	C	FORWARD SOLUTION OF OBJECT ROWS IN E ARRAY	8600	614		
	156	NEIL=6*MORT+3	8600	615		
600		DO 127 I=1,3	8600	616		
		SQR=1./SQRT(F(I,I))	8600	617		
		DO 128 J=I,NEIL	8600	618		
		E(I,J)=E(I,J)*SQR	8600	619		
	128	CONTINUE	8600	620		
605		E(I,58)=E(I,58)*SQR	8600	621		

PROGRAM 8600

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		IF(I-3) 160,161,161	8600	622
	160	IP1=I+1	8600	623
		DO 127 M=IP1,3	8600	624
		DO 162 J=M,NEIL	8600	625
610		E(M,J)=E(M,J)-E(I,M)*E(I,J)	8600	626
	162	CONTINUE	8600	627
		E(M,58)=E(M,58)-E(I,4)*E(I,58)	8600	628
	127	CONTINUE	8600	629
	C	EFFECT OF OBJECT ROWS ON PERTINENT CAMERA ROWS	8600	630
615	161	DO 163 J=1,MORT	8600	631
		IP1=D(I,J)	8600	632
		IF(IPHO-43) 205,205,206	8600	633
	206	IF(ME+42-IPHO) 207,208,208	8600	634
	207	LAST=6*IP1-6*(ME-1)	8600	635
620		GO TO 209	8600	636
	208	LAST=6*IP1-6*(IPHO-43)	8600	637
		GO TO 209	8600	638
	205	LAST=6*IP1	8600	639
	209	M=LAST-5	8600	640
625		DO 163 NROW=1,3	8600	641
		NEIL=5*J-3	8600	642
		DO 163 I=M, LAST	8600	643
		NMI=J	8600	644
		NCON=NEIL	8600	645
630		NEIL=NEIL+1	8600	646
		A(I,LLL)=A(I,LLL)-E(NROW,NEIL)*E(NROW,58)	8600	647
		DO 164 JOYCE=I, LAST	8600	648
		NCON=NCON+1	8600	649
		A(I,JOYCE)=A(I,JOYCE)-E(NROW,NEIL)*E(NROW,NCON)	8600	650
635	164	CONTINUE	8600	651
		IF(J-MORT) 165,163,163	8600	652
	165	NMI=NMI+1	8600	653
		IF(NMI-MORT) 167,167,163	8600	654
	167	IS=0(1,NMI)	8600	655
640		IF(IPHO-43) 210,210,211	8600	656
	211	IF(ME+42-IPHO) 212,213,213	8600	657
	212	NU=6*IS-6*(ME-1)	8600	658
		GO TO 214	8600	659
	213	NU=6*IS-6*(IPHO-43)	8600	660
645		GO TO 214	8600	661
	210	NU=6*IS	8600	662
	214	IMAGE=NU-5	8600	663
		DO 168 JOYCE=IMAGE,NU	8600	664
		NCON=NCON+1	8600	665
650		A(I,JOYCE)=A(I,JOYCE)-E(NROW,NEIL)*E(NROW,NCON)	8600	666
	168	CONTINUE	8600	667
		GO TO 165	8600	668
	163	CONTINUE	8600	669
		IF(KC) 125,125,169	8600	670
655	C	FORWARD SOLUTION OF CAMERA ROWS FOR THE RESET PLATE	8600	671
	169	K=0	8600	672
		IF(IPHO-43) 170,170,171	8600	673
	170	N=6*ME	8600	674
		GO TO 174	8600	675
660	171	IF(ME+42-IPHO) 172,173,173	8600	676

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PROGRAM		CDC 6610 FTN V3.0-324 OPT=2		04/02/75 20.40.54.		PAGE		13	
	172	N=6				8600	677		
		K=1				8600	678		
		GO TO 174				8600	679		
	173	N=6*ME-6*(IPHO-43)				8600	680		
665	174	M=N-5				8600	681		
		NCON=M-1+6*LOS				8600	682		
		IF(NCON.GT.258) NCON=258				8600	683		
		DO 175 I=M,N				8600	684		
		SQR=1./SQRT(A(I,I))				8600	685		
670		DO 176 J=I,NCON				8600	686		
		A(I,J)=A(I,J)*SQR				8600	687		
	176	CONTINUE				8600	688		
		A(I,LLL)=A(I,LLL)*SQR				8600	689		
		A(I,I)=SQR				8600	690		
675		IF(I-N) 177,180,180				8600	691		
	177	IP1=I+1				8600	692		
		DO 175 L=IP1,N				8600	693		
		DO 193 J=L,NCON				8600	694		
		A(L,J)=A(L,J)-A(I,L)*A(I,J)				8600	695		
680	193	CONTINUE				8600	696		
		A(L,LLL)=A(L,LLL)-A(I,L)*A(I,LLL)				8600	697		
	175	CONTINUE				8600	698		
	180	IF(K) 178,178,181				8600	699		
	181	DO 320 I=M,N				8600	700		
685		DO 186 J=I,NCON				8600	701		
		A(J,I)=A(I,J)				8600	702		
	186	CONTINUE				8600	703		
		A(LLL,I)=A(I,LLL)				8600	704		
	320	CONTINUE				8600	705		
690		CALL WRITHS(12,A,1554,ME)				8600S	9		
	C	EFFECT OF RESET PLATE ON ROWS OF FOLLOWING CAMERAS				8600	707		
	178	IF(ME-IPHO) 182,179,179				8600	708		
	182	NEIL=N+1				8600	709		
		DO 183 I=M,N				8600	710		
695		IF(I-N) 184,185,185				8600	711		
	185	IF(K) 184,184,305				8600S	10		
	305	DO 196 L=NEIL,NCON				8600	717		
		DO 197 J=L,NCON				8600	718		
		A(L-6,J-6)=A(L,J)-A(L,I)*A(J,I)				8600	719		
700	197	CONTINUE				8600	720		
		A(L-6,LLL)=A(L,LLL)-A(L,I)*A(LLL,I)				8600	721		
	196	CONTINUE				8600	722		
		JOYCE=NCON-5				8600	723		
		DO 298 L=1,NCON				8600	724		
705		DO 298 J=JOYCE,NCON				8600	725		
		A(L,J)=0.				8600	726		
	298	CONTINUE				8600	727		
		DO 299 L=JOYCE,NCON				8600	728		
		A(L,LLL)=0.				8600	729		
710	299	CONTINUE				8600	730		
		GO TO 183				8600	731		
	184	DO 194 L=NEIL,NCON				8600	732		
		DO 195 J=L,NCON				8600	733		
		A(L,J)=A(L,J)-A(I,L)*A(I,J)				8600	734		
715	195	CONTINUE				8600	735		

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      A(L,LLL)=A(L,LLL)-A(I,L)*A(I,LLL)      B600 736
194 CONTINUE      B600 737
183 CONTINUE      B600 738
      ME=ME+1      B600 739
720      KC=0      B600 740
      GO TO 105      B600 741
C      BACK SOLUTION OF CAMERA ROWS AND ADD RESULTS TO CAM ARRAY      B600 742
179 SCALE=CAM(1,5)      B600 743
      IF(IPHO-43)198,199,199      B600 744
725      198 K=JOYCE=6*IPHO      B600 745
      LAST=IPHO      B600 746
      GO TO 215      B600 747
199 K=JOYCE=258      B600 748
      LAST=43      B600 749
730      215 SAVE=1./A(JOYCE,JOYCE)      B600 750
      PRINT 556,ITERAT,A(JOYCE,LL),SAVE      B600 751
      ME=1      B600 752
225 DO 216 NU=ME,LAST      B600 753
      NROW=IPHO+1-NU      B600 754
735      IF(NU.GT.LOS) JOYCE=JOYCE-5      B600 755
      IF(JOYCE-6*LOS)188,189,189      B600 756
188 JOYCE=6*LOS      B600 757
189 DO 216 I=1,6      B600 758
      IF(NU.EQ.1.AND.I.EQ.1)GO TO 217      B600 759
740      M=K      B600 760
      K=K-1      B600 761
      DO 221 J=M,JOYCE      B600 762
      A(K,LLL)=A(K,LLL)-A(J,LLL)*A(K,J)      B600 763
221 CONTINUE      B600 764
745      217 A(K,LLL)=A(K,LLL)*A(K,K)      B600 765
      IF(I-3)218,218,219      B600 766
218 J=6-I      B600 767
      CAM(NROW,J)=CAM(NROW,J)+A(I,LLL)*SCALE      B600 768
      GO TO 216      B600 769
750      219 J=12-I      B600 770
      FK=SQRT(1.-A(K,LLL)*A(K,LLL))      B600 771
      SAVE=CAM(NROW,J)*FK + CAM(NROW,J+3)*A(K,LLL)      B600 772
      CAM(NROW,J+3)=CAM(NROW,J+3)*FK - CAM(NROW,J)*A(K,LLL)      B600 773
      CAM(NROW,J)=SAVE      B600 774
755      IF(NU.EQ.1.AND.I.EQ.4)GO TO 222      B600 775
      IF(ABS(A(K,LLL))-ABS(G(12)01))216,216,222      B600 776
222 NMI=NROW      B600 777
      G(1201)=A(K,LLL)      B600 778
216 CONTINUE      B600 779
760      ME=LAST=LAST+1      B600 780
      IF(ME-IPHO)220,220,227      B600 781
220 NROW=IPHO+1-ME      B600 782
      CALL READMS(12,A,1554,NROW)      B600S 11
      DO 223 J=7,258      B600 784
765      I=265-J      B600 785
      A(I,LLL)=A(I-6,LLL)      B600 786
223 CONTINUE      B600 787
307 DO 224 I=1,6      B600 792
      DO 224 J=I,259      B600 793
770      A(I,J)=A(J,I)      B600 794

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	224	CONTINUE	B600	795
		K=7	B600	796
		GO TO 225	B600	797
	227	IS=CAM(NMI,1)	B600	798
775		PRINT 533,ITERAT,G(12001),IS	B600	799
		IF (ABS(G(12001))-0.00001)230,230,228	B600	800
	228	ITERAT=ITERAT+1	B600	801
		IF (ITERAT-MAX)229,229,230	B600	802
	229	IRE=1	B600	803
780		GO TO 231	B600	804
	230	IRE=2	B600	805
	C		B600	806
	C	BLOCK ORIENTATION SOLUTION COMPLETED	B600	807
	C		B600	808
785		PRINT 541	B600	809
		DO 232 I=1,IPHO	B600	810
		IS=CAM(I,1)	B600	811
		PRINT 561,IS,(CAM(I,J),J=3,5)	A600	6
	232	CONTINUE	B600	813
790		PRINT 539	B600	814
		DO 233 I=1,IPHO	B600	815
		IS=CAM(I,1)	B600	816
		PRINT 557,IS,(CAM(I,J),J=5,8)	B600	817
		PRINT 557,IS,(CAM(I,J),J=9,11)	B600	818
795	233	CONTINUE	B600	819
		PRINT 547	B600	820
		PRINT 534	B600	821
		PRINT 548	B600	822
	C		B600	823
800	C	INTERSECTION OF OBJECTS USED IN BLOCK ORIENTATION SOLUTION	B600	824
	C		B600	825
	231	INSECT=1	B600	826
		DO 329 I=220,225	B600	827
		DO 329 J=1,200	B600	828
805		A(I,J)=0.	B600	829
	329	CONTINUE	B600	830
		KC=0	B600	831
		ITEST=0	B600	832
		GO TO 234	B600	833
810	360	IF (NA.EQ.0) GO TO 268	B600	834
	C	SET UP IMAGES OF OBJECT TO BE COMPUTED BY INTERSECTION	B600	835
	355	IMAGE=1	B600	836
	361	A(1,IMAGE)=B(1,N)	B600	837
		A(2,IMAGE)=B(2,N)	B600	838
815		A(3,IMAGE)=B(3,N)	B600	839
	270	J=A(1,IMAGE)*.0000001	B600	840
		FK=J	B600	841
		DO 235 L=1,IPHO	B600	842
		IF (FK-CAM(L,1))235,236,235	B600	843
820	235	CONTINUE	B600	844
	236	A(4,IMAGE)=L	B600	845
		A(5,IMAGE)=20*(L-1) - 863*((L-1)/43)	B600	846
		IF (LARRY)358,358,357	B600	847
	357	A(6,IMAGE)=CAM(L,2)	B600	848
825		GO TO 359	B600	849

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PROGRAM B600

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358 A(6,IMAGE)=FL
359 FK=J*10.00000
      A(7,IMAGE)=A(1,IMAGE)-FK
      IF(IOTHER.EQ.1) GO TO 313
830      IF(A(7,1)-A(7,IMAGE))237,238,237
      238 N=N+1
      IMAGE=IMAGE+1
      IF(N-NA/3)361,361,246
      246 KC=1
835      237 IMAGE=IMAGE-1
      IS=A(7,1)
      P(11,1)=P(11,3)=0.
      DO 287 NU=1,LINE
      IF(A(7,1)-G(6*NU-5))287,238,287
840      287 CONTINUE
      GO TO (241,242),IRE
      241 IF(G(6*NU-1).NE.0.0.AND.G(6*NU).NE.0.0) GO TO 267
      P COEFFICIENTS, CONSTANT TERMS, CONTRIBUTIONS TO NORMAL EQUATIONS
      242 DO 124 I=1,3
845      DO 124 J=I,4
      E(I,J)=0.
      124 CONTINUE
      DO 362 M=1,IMAGE
      K=A(5,M)
850      IF(IOTHER.EQ.1) GO TO 323
      DO 289 I=1,3
      J=6*NU-5+I
      C(I,K+16)=G(J)-C(I,K+1)
      289 CONTINUE
855      J=K+4
      DO 239 I=1,3
      C(I,K+17)=C(1,J)*C(1,K+16)+C(2,J)*C(2,K+16)+C(3,J)*C(3,K+16)
      J=J+1
      239 CONTINUE
860      323 IF(IOTHER.EQ.0)GO TO 363
      IF(A(10,M).EQ.0.0)GO TO 352
      363 DO 240 J=1,3
      P(1,J)=(A(2,M)*C(J,K+6)+A(5,M)*C(J,K+4))/C(3,K+17)
      P(2,J)=(A(3,M)*C(J,K+6)+A(5,M)*C(J,K+5))/C(3,K+17)
865      240 CONTINUE
      L=A(4,M)
      P(1,4)=P(1,1)*CAM(L,3)+P(1,2)*CAM(L,4)+P(1,3)*CAM(L,5)
      P(2,4)=P(2,1)*CAM(L,3)+P(2,2)*CAM(L,4)+P(2,3)*CAM(L,5)
      DO 245 I=1,3
870      DO 245 J=I,4
      DO 245 L=1,2
      E(I,J)=E(I,J)+P(L,I)*P(L,J)
      245 CONTINUE
      362 CONTINUE
875      C SOLUTION OF NORMAL EQUATIONS FOR XYZ
      311 DO 248 I=1,3
      SQR = 1./SQRT(E(I,I))
      DO 249 J=I,4
      E(I,J)=E(I,J)*SQR
880      249 CONTINUE

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PROGRAM		CDC 6600 FTN V3.0-324 OPT=2 04/02/75 20.40.54.		PAGE	17
		E(I,I)=SQR	8600	964	
		IF(I-3)250,251,251	8600	965	
250		IP1=I+1	8600	966	
		DO 248 M=IP1,3	8600	967	
885		DO 248 J=M,4	8600	968	
		E(M,J)=E(M,J)-E(I,M)*E(I,J)	8600	969	
248		CONTINUE	8600	970	
251		E(3,4)=E(3,4)*E(3,3)	8600	971	
		DO 252 I=1,2	8600	972	
890		NMI=3-I	8600	973	
		NMIP1=NMI+1	8600	974	
		DO 253 J=NMI,3	8600	975	
		E(NMI,4)=E(NMI,4)-E(J,4)*E(NMI,J)	8600	976	
253		CONTINUE	8600	977	
895		E(NMI,4)=E(NMI,4)*E(NMI,NMI)	8600	978	
252		CONTINUE	8600	979	
		IF(IOTHER.EQ.1.AND.IGO.EQ.1) GO TO 274	8600	980	
		IF(IOTHER.EQ.1.AND.IGO.EQ.2) GO TO 276	8600	981	
	C	TEST TO TERMINATE OBJECT INTERSECTION SOLUTION	8600	982	
900		SAVE=ABS(E(1,4)-G(6*NU-4))*(-A(6,IMAGE)/C(3,K+17))	8600	983	
		IF(SAVE-.000001)257,257,258	8600	984	
257		SAVE=ABS(E(2,4)-G(6*NU-3))*(-A(6,IMAGE)/C(3,K+17))	8600	985	
		IF(SAVE-.000001)259,259,258	8600	986	
258		NEIL=2	8600	987	
905		GO TO 273	8600	988	
259		NEIL=1	8600	989	
273		GO TO (243,264),IRE	8600	990	
	C	BLOCK ORIENTATION SOLUTION NOT COMPLETED - UPDATE ONLY NONCONTROL	8600	991	
	C	XYZ FOR ITERATION OF THE BLOCK ORIENTATION SOLUTION	8600	992	
910		243 IF(G(6*NU-1))260,244,260	8600	993	
		244 G(6*NU-4)=E(1,4)	8600	994	
		G(6*NU-3)=E(2,4)	8600	995	
		260 IF(G(6*NU))262,261,262	8600	996	
		261 G(6*NU-2)=E(3,4)	8600	997	
915		262 GO TO (267,242),NEIL	8600	998	
	C	BLOCK ORIENTATION SOLUTION COMPLETED	8600	999	
		264 IF(A(7,1).EQ.G(6*LINE-5)) ITEST=1	8600	1000	
		IF(KB)280,280,285	8600	1001	
		280 IF(G(6*NU-1).NE.0.0.AND.3(6*NU).NE.0.0) GO TO 282	8600	1002	
920		IF(G(6*NU-1).NE.0.0) GO TO 281	8600	1003	
		IF(G(6*NU).EQ.0.0) GO TO 308	8600	1004	
		G(12003)=G(6*NU-2)	8600	1005	
		PRINT 560,IS,G(12003)	8600	1006	
		GO TO 284	8600	1007	
925		308 PRINT 562	8600	1008	
		GO TO 284	8600	1009	
		281 G(12001)=G(6*NU-4)	8600	1010	
		G(12002)=G(6*NU-3)	8600	1011	
		PRINT 554,IS,G(12001),G(12002)	8600	1012	
930		GO TO 284	8600	1013	
		282 PRINT 554,IS,G(6*NU-4),G(6*NU-3),G(6*NU-2)	8600	1014	
		CALL QBUF(1)	8600	1015	
		ENCODE(80,561,BUF(IBUF))IS,G(6*NU-4),G(6*NU-3),G(6*NU-2),ITEST	8600	1016	
		284 KB=1	8600	1017	
935		285 GO TO (346,265),NEIL	8600	1018	

B16

PROGRAM		9600	CDC 6600 FPN V3.0-324 OPT=2 04/02/75 20.40.54.		PAGE	19
	C		INTERSECTION OF OBJECTS NOT USED IN THE BLOCK ORIENTATION SOLUTION	8600	1014	
	C			8600	1015	
	C			8600	1016	
995			PRINT 530	8600	1017	
			PRINT 534	8600	1018	
			PRINT 548	8600	1019	
			IOther=IMAGE=IGO=MORT=1	8600	1020	
			JOYCE=LINE=0	8600	1021	
	C		READ IN IMAGES OF THE OBJECT	8600	1022	
1000		316	CALL DRUF(1)	8600	1023	
			DECODE(80,526,8UFF(IXBUF))(A(J,IMAGE),J=1,3)	8600	1024	
			IF(A(1,IMAGE).EQ.0.0) GO TO 315	8600	1025	
			GO TO 270	8600	1026	
		313	IF(A(7,1)-A(7,IMAGE)) 315,314,315	8600	1027	
1005		314	IMAGE=IMAGE+1	8600	1028	
			GO TO 316	8600	1029	
		315	IMAGE=IMAGE-1	8600	1030	
			IF(IMAGE.EQ.0) GO TO 350	8600	1031	
			IS=A(7,1)	8600	1032	
1010			PRINT 562	8600	1033	
			DO 327 M=1,IMAGE	8600	1034	
			A(10,M)=1.	8600	1035	
			K=A(5,M)	8600	1036	
			L=A(4,M)	8600	1037	
1015			DO 328 J=1,3	8600	1038	
			C(J,K+1)=CAM(L,J+2)	8600	1039	
			C(J,K+2)=CAM(L,J+5)	8600	1040	
			C(J,K+3)=CAM(L,J+8)	8600	1041	
		328	CONTINUE	8600	1042	
1020			C(1,K+4)=C(2,K+3)*C(3,K+3)	8600	1043	
			C(1,K+5)=-C(2,K+3)*C(3,K+2)	8600	1044	
			C(1,K+6)=C(2,K+2)	8600	1045	
			C(2,K+4)=C(1,K+3)*C(3,K+2) + C(1,K+2)*C(2,K+2)*C(3,K+3)	8600	1046	
			C(2,K+5)=C(1,K+3)*C(3,K+3) - C(1,K+2)*C(2,K+2)*C(3,K+2)	8600	1047	
1025			C(2,K+6)=-C(1,K+2)*C(2,K+3)	8600	1048	
			C(3,K+4)=C(1,K+2)*C(3,K+2) - C(2,K+2)*C(3,K+3)*C(1,K+3)	8600	1049	
			C(3,K+5)=C(1,K+2)*C(3,K+3) + C(2,K+2)*C(3,K+2)*C(1,K+3)	8600	1050	
			C(3,K+6)=C(1,K+3)*C(2,K+3)	8600	1051	
			C(3,K+17)=1.	8600	1052	
1030		327	CONTINUE	8600	1053	
	C		COMPUTE L.S. SOLUTION OF XYZ USING A3B EQJAL 1	8600	1054	
			GO TO 242	8600	1055	
		274	G(12001)=E(1,4)	8600	1056	
			G(12002)=E(2,4)	8600	1057	
1035			G(12003)=E(3,4)	8600	1058	
	C		COMPUTE L.S. SOLUTION OF XYZ USING COMPUTED A3B	8600	1059	
			IGO=2	8600	1060	
		346	DO 325 M=1,IMAGE	8600	1061	
			K=A(5,M)	8600	1062	
1040			DO 326 I=1,3	8600	1063	
			C(I,K+16)=E(I,4)-C(I,K+1)	8600	1064	
		326	CONTINUE	8600	1065	
			J=K+4	8600	1066	
			DO 325 I=1,3	8600	1067	
1045			C(I,K+17)=C(1,J)*C(1,K+16)+C(2,J)*C(2,K+16)+C(3,J)*C(3,K+16)	8600	1068	

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B 10

PROGRAM B600

CDC 6630 FTN V3.0-324 OPT=2 04/02/75 20.40.54.

PAGE 20

J=J+1
 325 CONTINUE
 IF(IOTHER.EQ.0) GO TO 266
 GO TO (242,347),MORT
 1050 C TEST TO TERMINATE OBJECT INTERSECTION SOLUTION
 276 SAVE=ABS(E(1,4)-G(12001)) * (-A(6,IMAGE)/C(3,K+17))
 IF(SAVE-.000001)330,330,274
 330 SAVE=ABS(E(2,4)-G(12002)) * (-A(6,IMAGE)/C(3,K+17))
 IF(SAVE-.000001)331,331,274
 1055 C TERMINATION TEST GOOD. COMPUTE PLATE RESIDUALS
 331 MORT=2
 GO TO 346
 347 DO 332 M=1,IMAGE
 IF(A(10,M).EQ.0.0) GO TO 332
 1060 K=A(5,M)
 A(8,M)=(A(2,M)+A(6,M)*C(1,<+17)/C(3,K+17))*1000000.
 A(9,M)=(A(3,M)+A(6,M)*C(2,<+17)/C(3,K+17))*1000000.
 332 CONTINUE
 C DETERMINE MAXIMUM PLATE RESIDUAL AND TEST AGAINST RESIDUAL LIMIT
 1065 N=8
 M=J=1
 DO 275 I=8,9
 277 M=M+1
 IF(M-IMAGE)278,278,279
 1070 278 IF(ABS(A(N,J))-ABS(A(I,M)))319,277,277
 319 N=I
 J=M
 GO TO 277
 279 M=0
 1075 275 CONTINUE
 IF(ABS(A(N,J))-RESID)166,166,226
 C BAD IMAGE
 226 JOYCE=JOYCE+1
 IF(JOYCE-1)333,333,334
 1080 333 IF(IMAGE-3)334,334,335
 335 A(8,J)=A(9,J)=A(10,J)=0.
 MORT=1
 GO TO 274
 334 A(10,J)=2.
 1085 C OUTPUT XYZ AND PLATE RESIDUALS
 166 IP1=A(1,1)
 IF(A(10,1)-1.)336,337,338
 336 PRINT 549,IS,E(1,4),E(2,4),E(3,4),IP1
 GO TO 339
 1090 337 PRINT 553,IS,E(1,4),E(2,4),E(3,4),IP1,A(8,1),A(9,1)
 GO TO 339
 338 PRINT 550,IS,E(1,4),E(2,4),E(3,4),IP1,A(8,1),A(9,1)
 339 CALL GRUF(1)
 ENCODE(80,561,8UF(1BUF)) IS,E(1,4),E(2,4),E(3,4)
 1095 DO 340 M=2,IMAGE
 IP1=A(1,M)
 IF(A(10,M)-1.)341,342,343
 341 PRINT 551,IP1
 GO TO 340
 1100 342 PRINT 536,IP1,A(8,M),A(9,M)

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B21

PROGRAM , , , , 8600

CDC 6610 FTN V3.0-324 OPT=2 04/02/75 20.40.54.

PAGE 21

GO TO 340
 343 PRINT 555,IP1,A(8,M),A(9,M)
 340 CONTINUE
 344 LINE=LINE+1
 1105 C RECYCLE FOR NEXT OTHER OBJECT
 IF(A(1,IMAGE+1).EQ.0.0) GO TO 350
 DO 345 I=1,7
 A(I,1)=A(I,IMAGE+1)
 345 CONTINUE
 1110 JOYCE=0
 IGO=IMAGE=MORT=1
 GO TO 314
 C
 C BLOCK ADJUSTMENT COMPLETED
 1115 C
 350 PRINT 552,LINE
 IF(INVER.EQ.0) GO TO 366
 DO 365 I=1,IPHO
 IS=CAM(I,1)
 1120 CALL OBUF(1)
 ENCODE(80,561,BUF(IBUF)) IS,(CAM(I,J),J=3,5),INVER
 CALL OBUF(1)
 ENCODE(80,557,BUF(IBUF)) IS,(CAM(I,J),J=6,8)
 CALL OBUF(1)
 1125 ENCODE(80,557,BUF(IBUF)) IS,(CAM(I,J),J=9,11)
 365 CONTINUE
 366 PRINT 542
 CALL OBUF(0)
 GO TO 1000
 1130 C
 C FORMAT STATEMENTS
 524 FORMAT(1X,I1,1X,E14.7,2(3X,F2.1),2X,F2.0,3X,I1,F6.0,8X,I1,9X,I1)
 525 FORMAT(7X,F3.0,3(2X,F1.0),3X,E14.7)
 1135 526 FORMAT(1X,F9.0,2(2X,E14.7),37X,I1)
 527 FORMAT(4X,F6.0,3(1X,F12.3),30X,I1)
 528 FORMAT(/32H GROUND COORDINATES MISSING FOR I6, 5H-STOP/)
 529 FORMAT(44H PROVISIONAL GROUND COORDINATES ENTERED FOR I4, 35H OBJE
 1CTS. EXCEEDS 2000 LIMIT--STOP/)
 1140 530 FORMAT(1H1,28X,56H*** INTERSECTION OF OBJECTS NOT USED IN SO.UTI
 10N ***)
 531 FORMAT(8A10)
 532 FORMAT(/50H ORIENTATION PARAMETER CORRECTION LIMIT IS 0.0001/)
 533 FORMAT(14H PROGRAM PASS 11,46H PRODUCES A MAXIMUM ORIENTATION CORR
 1ECTION OF E14.7, 11H FOR PLATE I3)
 1145 534 FORMAT(38X,37H (SECANT PLANE COORDINATES - MICRONS)/)
 535 FORMAT(/7H PLATE I3, 36H NEEDS OVER 5 RESECTION PASSES--STOP)
 536 FORMAT(48X,I16,F16.3,F19.3)
 537 FORMAT(/8H OBJECT I6, 31H APPEARS ON OVER 9 PHOTOS--STOP)
 1150 538 FORMAT(/33H RMS RESIDUAL FOR ENTIRE BLOCK = E14.7, 8H MICRONS)
 539 FORMAT(/52H PLATE OMEGA PHI KAPPA/)
 541 FORMAT(/44H PLATE XO YO ZO/)
 542 FORMAT(/54H BLOCK ADJUSTMENT COMPLETED)
 543 FORMAT(/16H BLOCK CONTAINS I3,17H PHOTOGRAPHS AND I4,8H OBJECTS/)
 1155 544 FORMAT(/27H BLOCK ADJUSTMENT CONTAINS I4, 47H OBJECTS AND EXCEEDS

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B22

PROGRAM	8600	CDC 6600 FTN V3.0-324	OPT=2	04/02/75	20.40.54.	PAGE	22
	1 LIMIT OF 1978--STOP)					8600	1170
	545 FORMAT(/7H PLATE I3, 29H EXCEEDS 30-IMAGE LIMIT--STOP)					8600	8
	546 FORMAT(24H * DISK (PARITY) ERROR *)					8600	1173
1160	547 FORMAT(1H1,30X,52H*** INTERSECTION OF OBJECTS USED IN SOLUTION 1 ***)					8600	1174
	548 FORMAT(* OBJECT X GROUND Y GROUND Z GROUND 1 IMAGE VX PLATE RESID VY PLATE RESID *)					8600	1175
	549 FORMAT(1X,I7,F14.3,2F13.3,I16,28H OVER LIMIT--IMAGE DISCARDED)					8600	1176
1165	550 FORMAT(1X,I7,F14.3,2F13.3,I16,2H *,F14.3,F19.3)					8600	1177
	551 FORMAT(48X,I16,28H OVER LIMIT--IMAGE DISCARDED)					8600	1178
	552 FORMAT(/40H TOTAL NUMBER OF INTERSECTED OBJECTS IS I4)					8600	1179
	553 FORMAT(1X,I7,F14.3,2F13.3,I16,F16.3,F19.3)					8600	1180
	554 FORMAT(///1X,I7,1HT,3F13.3)					8600	1181
1170	555 FORMAT(48X,I16,2H *,F14.3,F19.3)					8600	1182
	556 FORMAT(/14H PROGRAM PASS I1, 19H LAST PLATE OZO IS E14.7, 12H DIVI 1DED BY E14.7)					8600	1183
	557 FORMAT(1X,I9,2X,E14.7,2X,E14.7,2X,E14.7)					8600	1184
	558 FORMAT(4X,F6.0,2X,F2.0,2X,F2.0,61X,I1)					8600	1185
1175	560 FORMAT(///1X,I7,1HT,F39.3)					8600	1186
	561 FORMAT(1X,I9,1X,F12.3,1X,F12.3,1X,F12.3,33X,I1)					8600	1187
	562 FORMAT(1H //)					8600	1188
	567 FORMAT(/23H POSITION WEIGHT VARIES/)					8600	1189
	568 FORMAT(/25H POSITION WEIGHT CONSTANT/)					8600	19
1180	569 FORMAT(1H1,8A10)					8600	1191
	570 FORMAT(/40H OVER 250 WEIGHTED OBJECTS ENTERED--STOP)					8600	9
	572 FORMAT(51H NUMBER OF PHOTOS IN ORDERED STRIP EXCEEDS 20--STOP)					8600	10
	573 FORMAT(54H CONTROL EQUATION XY Z (0=NO CONSTRAINT))					8600	1194
	574 FORMAT(2X,I6,8X,I2,8X,I2,5X,I2)					8600	1195
1185	575 FORMAT(60X,13H RMS OBJECT= E14.7,8H MICRONS)					8600	1196
	576 FORMAT(15H FL CONSTANT = E14.7,24H MAXIMUM ITERATIONS = I2,3)H 1 RESIDUAL LIMIT (MICRONS) = E14.7)					8600	1197
	577 FORMAT(28H RESOLUTION WEIGHTS WT12 = E14.7,16H WT12P = E14.77)					8600	1198
	578 FORMAT(1H1,26H PLATE RMS (MICRONS) /)					8600	1199
	END					8600	1200
						8600	1201
						8600	1202
						8600	1203
						8600	1204

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B23

SUBROUTINE DBUF

CDC 6610 FTN V3.0-324 OPT=2 04/02/75 20.40.54.

PAGE 1

SUBROUTINE DBUF (NORECS)

C

C THIS PROGRAM IS SET UP FOR A DOUBLE BUFFER AREA ALTHOUGH IT IS USING
C WAIT MODE INSTRUCTIONS. TO BE CHANGED IN THE FUTURE.

5

C

COMMON /CDBUF/ LENGT,NEXT,IFIRST,IXBUF,BUFF(1024),IQ,KS

DATA (ICOUNT=0)

DATA (IT3=24012005360000000000), (IEF=10000000000000000000),

1 (IPR=20000000000000000000)

10

C

IF (NORECS) 70,10,70

10 CALL LTRIO (IQ,1110,BUFF(IFIRST),BUFF(IFIRST+511),KS)

IF (KS .LT. 0) GO TO 76

IF ((KS.AND.IPR) .NE. 0) PRINT 100,IQ

15

IF ((KS.AND.IEF) .NE. 0) GO TO 60

IFIRST = MOD(IFIRST+512,1024)

ICOUNT = 0

RETURN

60 ICOUNT = ICOUNT + 1

20

IF (ICOUNT .LT. 2) GO TO 10

PRINT 64

CALL LTRIO (IT3,1150,A,B,JS)

STOP

70 IF (MOD(LENGT,512)) 79,74,79

25

74 CALL LTRIO (IQ,1110,BUFF(IFIRST),BUFF(IFIRST+511),KS)

IF (KS .LT. 0) GO TO 76

IF ((KS.AND.IPR) .NE. 0) PRINT 100,IQ

IFIRST = MOD(IFIRST+512,1024)

30

79 LENGT = MOD(LENGT+8*NORECS,1024)

IXBUF = NEXT

NEXT = LENGT + 1

RETURN

76 PRINT 77,KS

STOP

35

100 FORMAT (/* TROUBLE IN INPJT TAPE * 020 /)

64 FORMAT(*1 JOB TERMINATED-- END OF DATA*)

77 FORMAT(*1 JOB ABORTED-- STATUS WORD * 020)

END

DBUF 2

DBUF 3

DBUF 4

DBUF 5

DBUF 6

DBUF 7

DBUF 8

DBUF 9

DBUF 10

DBUF 11

DBUF 12

DBUF 13

DBUF 14

DBUF 15

DBUF 16

DBUF1 1

DBUF 18

DBUF 19

DBUF 20

DBUF 21

DBUF 22

DBUF 23

DBUF 24

DBUF1 2

DBUF 26

DBUF 27

DBUF 28

DBUF1 3

DBUF1 4

DBUF 31

DBUF 32

DBUF 33

DBUF 34

DBUF 35

DBUF 36

DBUF 37

DBUF 38

DBUF 39

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B24

SUBROUTINE OBUF

CDC 6630 FTN V3.0-324 OPT=2 04/02/75 20.40.54.

PAGE 1

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SUBROUTINE OBUF (NORECS)
C
C THIS PROGRAM IS SET UP FOR A DOUBLE BUFFER AREA ALTHOUGH IT IS USING
C WAIT MODE INSTRUCTIONS. TO BE CHANGED IN THE FUTURE.
5 C
C COMMON /OBUF /LENGT,NEXT,IFIRST,IXBUF,BUFF(1024),IP,ENDFLQ
C
C IF (NORECS) 10,40,10
10 LENGT = LENGT + NORECS
IF (LENGT.GT.64) GO TO 20
IXBUF = NEXT
GO TO 30
20 CALL LTRIO (IP,1128,BUFF(IFIRST),BUFF(IFIRST+511),KS)
IF (KS .LT. 0) GO TO 80
15 IXBUF = IFIRST + MOD(IFIRST+512,1024)
LENGT = NORECS
30 NEXT = IXBUF + NORECS*8
RETURN
40 INDEX = IFIRST + (LENGT-NORECS)*8 - 1
20 CALL LTRIO (IP,1128,BUFF(IFIRST),BUFF(INDEX),KS)
IF (KS .LT. 0) GO TO 80
ENDFLQ = 0.
RETURN
80 PRINT 100,KS
25 STOP
100 FORMAT (*1 'JOB ABORTED-- STATUS WORD',J21)
END

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OBUF 2
OBUF 3
OBUF 4
OBUF 5
OBUF 6
OBUF 7
OBUF 8
OBUF 9
OBUF 10
OBUF 11
OBUF 12
OBUF 13
OBUF 14
OBUF 15
OBUF 1
OBUF 17
OBUF 18
OBUF 19
OBUF 20
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OBUF 22
OBUF 23
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OBUF 27
OBUF 28

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